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AEROMEDICAL HANDBOOK FOR AIRCREW

by

Gp Capt.T.G.Dobie

Deputy Director of Aviation Medicine (RAF)
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PREFACE

The purpose of this aeromedical handbook is to provide information on all the various aspects of aviation medicine which have an important bearing on the aircrew task. The author has concentrated on a practical approach to the subject in order to answer the questions most frequently posed by aviators. At the same time, due regard has been taken of the contents of the NATO Standardisation Agreement on aeromedical training for aircrew in order to ensure that the needs of that syllabus have been met.

The book is intended for use by aircrews throughout the NATO alliance who fly many different types of aircraft in various roles. The text has therefore been confined mainly to the important principles involved and any reference to equipment is only by way of example. Detailed information on aircrew equipment assemblies will be found in the appropriate National documents.

Training aids of this kind represent only a small part of the whole vast scheme of aeromedical care and advice which is available to NATO aircrews. The main key to the organisation is the local Flight Surgeon, Flight Medical Officer or other appropriate medical adviser, whatever title he may have, to whom aircrews should turn when they have a query or problem. It is safe to say that he will always be ready and willing to give his expert advice and guidance.

ACKNOWLEDGMENTS

In writing this handbook, I have been especially fortunate in that many of my friends have been generous enough to make suggestions or have commented on parts of the manuscript. In particular, I wish to pay tribute to five distinguished aeromedical experts who agreed to review the whole manuscript on behalf of the Aerospace Medical Panel of AGARD on whose behalf the handbook was written, namely,

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Brigadier General Professor Dr E.A.Lauschner, German Air Force MC

Brigadier General J.Talbot, United States Air Force MC

Brigadier General Professor A.Scano, Italian Air Force MC

Colonel Professor F.Violette, French Air Force MC

Their guidance has been invaluable but any final inaccuracies are entirely mine.

I should also like to thank Group Captain T.C.D.Whiteside, Royal College of Physicians Professor of Aviation Medicine in the Royal Air Force and Chairman of the Aerospace Medical Panel and my many friends and colleagues at the Royal Air Force Institute of Aviation Medicine, Farnborough for their help and encouragement.

Finally I wish to thank my wife and daughters for their patience and help in correcting draft copies of the book; their good humour made the task possible.

Not least, however, I thank you the reader and wish you well in your chosen career in aviation.

T.G.Dobie

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GENERAL RULES OF MENTAL AND PHYSICAL HEALTH

INTRODUCTION

1. A modern aircraft is both complex and sophisticated and each member of its crew plays an essential part in ensuring that it can be operated to its maximum level of effectiveness. It is important, therefore, for crews to understand the many factors which go to make up the particular state of health necessary for maximum efficiency.

2. Flying exerts many diverse stresses, both mental and physical; as those of you who are already experienced aviators are well aware. These affect individuals differently and cause each person to vary from day to day in his state of fitness. It is perhaps best to begin by describing the salient characteristics of an effective aircrew member in order to gain a better understanding of the various factors which can influence his state of health.

THE AIRCREW TASK

3. In a military organisation the aircrew task may vary widely in its implications depending upon the role of the force and aircraft type. Strategic operations usually involve pre-planned sorties from well established bases, often associated with long periods of readiness on the ground. Tactical squadrons, on the other hand, frequently operate at short notice from temporary airstrips whose domestic facilities are minimal. Aircrew should therefore expect to meet all possible variables both in the air and on the ground; at home or during service in another country. Sooner or later they are also likely to be called upon to carry out flying instructional duties. This type of flying calls for different qualities but is equally important since the future of an air force depends upon the success of the training organisation.

4. These requirements call for dedication, flexibility and both physical and mental fitness, coupled with a high standard of training. Aircrew can then enter squadron service with both the knowledge and confidence which are required to meet the difficult and sometimes hazardous challenges which lie ahead.

HYGIENE AND PHYSICAL FITNESS

5. A high standard of hygiene is essential if the body is to remain healthy and free from infection. Great care must be taken in handling food and all cooking and eating utensils must be kept scrupulously clean to avoid stomach and bowel upsets. Personal hygiene promotes a feeling of well-being and care of the skin, scalp and teeth are very important adjuncts to good health. It also ensures that minor cuts and abrasions do not become infected; this is particularly important in the survival situation.

6. Physical exercise is an important means of stimulating the various systems of the body. The physiological stresses which an aviator will encounter, for example, during acceleration or heat stress, call for a circulatory system which can cope with these. Stimulation of the system by physical exercise is a good means of ensuring circulatory efficiency. The general toning-up of the muscles, heart and lungs is important to the aviator both in his daily working life and in preparation for the extra physical effort needed for arduous work in the field or in the survival situation. Sports which call for agility, balance and quick reaction as well as endurance provide an excellent means of keeping the body and the mind on top form.

DIET

7. Air forces are very conscious of the importance of a nutritious, well balanced diet for aircrew but ultimately the success of this programme depends upon the individual himself. It is also important that meals are taken at sensible intervals since long periods without food can induce fatigue and inefficiency; it is for this reason that a nourishing breakfast is important.

8. Obesity is a serious hazard which must be guarded against in all walks of life because of its detrimental effects on life span and general health. Periods of inactivity and boredom can lead to over-eating. This is a point to be borne in mind during standby and on long-range flights where a plentiful supply of food is carried. It is sensible to keep a regular check on body weight and adjust the diet to maintain the desired level. This is so much easier, safer and more agreeable than repeatedly having to diet strictly because of signs of obesity. Medical officers will advise on diets where necessary.

ALCOHOL AND TOBACCO

9. Alcohol in moderation can provide pleasure and relaxation for many people. It is, however, basically a depressant and adversely affects the normal functioning of the body tissues. Apart from the more obvious effects of excessive alcohol, even small amounts can have a detrimental effect on judgment, perception, speed of reaction and co-ordination. It is an excellent rule to allow 24 hours between the last alcoholic drink and take-off time and certainly no alcohol should be taken within 12 hours, since the after-effects are also hazardous. A certain time is needed to metabolise, or burn up, a given amount of alcohol and medication which makes an individual feel better does not, however, speed up the time taken to get rid of the alcohol. It is for this reason that the length of time between the last drink and take-off is so important.

10. Much has already been written in the press about the detrimental effects on health caused by tobacco. Apart from the long-term association with lung cancer and coronary heart disease, there are other effects which are less dramatic but also important. Chronic irritation of the lining of the nose and lungs by tobacco increases the likelihood of infection in these areas. To the aviator this is more than a nuisance factor since it affects his ability to cope with the effects of pressure changes on his ears and sinuses. It is also distressing to have even a mild irritant cough when using oxygen equipment. The incomplete combustion of tobacco

results in the smoker absorbing carbon monoxide which has a great affinity for haemoglobin, the oxygen-carrying constituent of the blood. Haemoglobin which is linked with carbon monoxide is not available for carrying oxygen; this aggravates the effects of hypoxia at a given altitude (see Chapter 15).

DRUGS AND DANGERS OF SELF-MEDICATION

11. Apart from the primary purpose for which drugs are intended, it is generally true to say that most of them also have some unwanted side-effects. People also vary to some extent in the way that the primary action of a drug affects them. In a few cases, there is a personal idiosyncrasy to a particular drug which means that the individual reacts in an unusual way and can be made very ill by it. For these reasons it is absolutely essential that aviators only take medicine which has been prescribed by their own medical officer or a physician who is aware of the fact that they fly. It is safest to assume that no one who is under treatment by drugs of any kind is fit to fly unless specific clearance has been given by a physician qualified in aviation medicine.

12. Self-medication is particularly dangerous. It not only carries the risk of unexpected drug effects but also the possible hazards to flying associated with the underlying illness. The possible dangers of drug side-effects may not always be obvious, particularly when a mixture of drugs is contained in an apparently innocuous compound on open sale to the public. The precautionary advice on the container does not take into consideration the especial problems associated with flying high performance aircraft. A few examples of groups of drugs and some of their side-effects will show this point more clearly and also highlight the more dangerous agents:

(a) 'COLD CURES' – Many of these contain antihistamines, often in sustained release form, which cause drowsiness and dizziness. The drowsiness can be particularly hazardous because it may not be recognised by the individual and may recur after a period of apparent alertness. Antispasmodic drugs are often included in these compounds and these can cause visual

disturbances. Some drugs used in the treatment of colds or influenza contain quinine which can adversely affect hearing and cause dizziness.

(b) ALLERGY TREATMENT – These drugs are antihistamines and have been described in sub-para (a).

(c) NASAL DECONGESTANTS – Either in drop or inhaler form, these usually contain stimulants and care should be taken not to use them indiscriminately.

(d) ANTACIDS – These may contain atropine which causes visual disturbances and may also contain sodium bicarbonate which liberates carbon dioxide and, at altitude, this may give rise to acute pain due to distension of the stomach.

(e) CONTROL OF DIARRHOEA – Many of these agents contain opiates which have a depressant effect on the brain; some may also cause nausea.

(f) STIMULANTS – Drugs such as benzedrine and dexedrine cause not only wakefulness but also nervousness and seriously impaired judgment in some cases. It is important to remember that these agents may be contained in certain drugs used for the treatment of obesity.

(g) TRANQUILISERS – These not only cause sleepiness, but also nausea, depression and visual disturbances, in some cases. Some of them produce intolerance to alcohol and may cause quite severe mental disturbance.

(h) SEDATIVES and HYPNOTICS – These cause sleepiness, sedation and impaired mental and physical activity, as would be expected. Minor sedation which remains during the recovery period might not be appreciated, however, and for that reason could be dangerous. Nausea and dizziness may also occur.

(j) ANTIBACTERIAL AGENTS – The drugs which are used to treat infections can cause nausea, vomiting and light-headedness.

(k) LOCAL ANAESTHETICS – Apart from the possibility of local discomfort in the wound as the anaesthetic wears off, they may cause excitement.

13. The above list is by no means complete but it does serve to highlight the possible effects associated with various drug

groups. You will see that many of these drugs must never be used without medical supervision and are totally incompatible with safe flying. The various air forces have their own particular regulations covering the use of drugs and the period of grounding associated with particular treatment. Medical officers who are responsible for the health and well-being of aircrew are fully conversant with all these drug effects. They also aim to ensure that their patients make a safe return to flying in the shortest possible time. It is important therefore to seek professional guidance when feeling 'off colour' or ill in any way and certainly not to indulge in self-medication.

THE IMPORTANCE OF MENTAL HEALTH IN AVIATION

14. Apart from the many physical and physiological stresses experienced by aircrew, flying imposes a considerable mental load. The efficient performance of a skilled task and correct decision making can only be achieved by a healthy, active, uncluttered mind. This means a happy, well-balanced, emotionally mature individual who has a normal pleasant home life; a personality which is well adjusted and able to cope with the various stresses and strains of community life. Air forces take great care to select such individuals in the first place but new stresses are imposed later, particularly when family commitments arise. An aviator who can himself cope with the hazards of flight may find that his family worries about his flying and their anxiety will be a further load for him to bear. Frequent detachments away from base may be interesting and exciting but, at the same time, can leave the family with anxieties and frustrations. These are all normal predictable problems and in most cases insight and understanding are all that is necessary to prevent the situation getting out of hand. A build up of stress may be insidious so that individuals can become quite ill from this cause before they realise it, simply because they may be unaware of having a problem. In other cases they may recognise their difficulties but are reluctant to seek help; perhaps they feel that only they react this way, so must be abnormal. Discussion can be a great help; both in prevention, by talking over new problems when they are first met and as a cure by

seeking help in the right places. Your medical officer will always be available to help whenever necessary; when in doubt go and see him.

REST AND SLEEP

15. It is important to get adequate rest and sleep and this is especially true before flying, to ensure maximum efficiency on the flight. Aviators who like to think that they can fly for long hours without adequate rest may not be aware of their seriously diminished levels of performance, since the effects of fatigue are so insidious. Certainly they may be able to remain awake for long hours under such circumstances but they are more accident-prone and less efficient generally. There are, of course, operational situations where long hours of duty may be unavoidable and we know that individuals can carry out remarkable feats of endurance on such occasions. They must, however, be prepared for the natural relaxation which tends to follow in the wake of particularly stressful or exciting events, especially when they are tired; this can lead to errors through lack of attention and is a potent cause of accidents. It is important, not only in the air but also when driving, to guard against the tendency to unwind suddenly when close to the security of home; this is a typical hazard for the over-tired person who is unprepared for it.

16. There are times particularly in strange, hot and noisy environments when it is difficult to get to sleep; this may be caused by changes of time zones (see paragraph 17). Every opportunity should be taken to rest comfortably however and sleep will usually follow. Difficulty with sleeping should be discussed with your medical officer, since it constitutes a potential flight safety hazard. This wakefulness might also be affecting a number of other individuals in similar circumstances and by changing the work routine or making local improvements, be overcome without loss of operational efficiency.

CLIMATIC AND TIME-SHIFT (ZONE CHANGE) EFFECTS OF TRAVEL

17. Climatic changes can have an immediate effect on an individual. For example, the exposure of an unacclimatised person to severe heat loads needs careful supervision. He will need to develop new habits, such as increasing his fluid intake and in some cases salt intake, to replace sweat loss. In the case of extreme cold, certain procedures will be necessary to prevent serious cold damage to the extremities (see Chapters 9 and 17). Lack of awareness of these problems inevitably leads to disaster. If you are selected for service in unfamiliar climatic areas your medical officer will be ready to provide appropriate advice.

18. Biological systems tend to have their own rhythms and can be adversely affected by disruption of these rhythms, particularly during long east to west and west to east flights. This causes fatigue and various practical difficulties at your destination because the local community is awake when you are normally asleep and you will have to adjust to these new circumstances. Wherever possible, flight plans should be made to minimise these effects en route. It is useful to stay on the base time schedule until reaching your destination; by doing so there is less likelihood of over-eating and more likelihood of restful sleep. The effects of zone changes are made worse by any anxiety about the trip so that it is important to reassure passengers and point out that they will soon adapt to their new environment.

CONCLUSIONS

19. You will probably already have been aware of much that has been said in this chapter, but it is useful to review the situation since knowledge and understanding provide an essential means of promoting flight safety and efficiency. The physical and mental well-being of a member of aircrew is essential to his ability to carry out a complex, skilled task. When in top mental and physical condition, he is the most important part of the weapon system; if not in good health he then becomes the weakest link in the chain.

- **WATCH YOUR DIET AND KEEP FIT.**
- **BEWARE THE EFFECTS OF ALCOHOL ON PERFORMANCE.**
- **ENSURE AN ADEQUATE SLEEP PATTERN.**
- **BEWARE THE HAZARDS OF SELF-MEDICATION.**
- **CONSULT YOUR MEDICAL OFFICER OR FLIGHT SURGEON.**

CHAPTER 2

PHYSICAL CHARACTERISTICS OF THE ATMOSPHERE

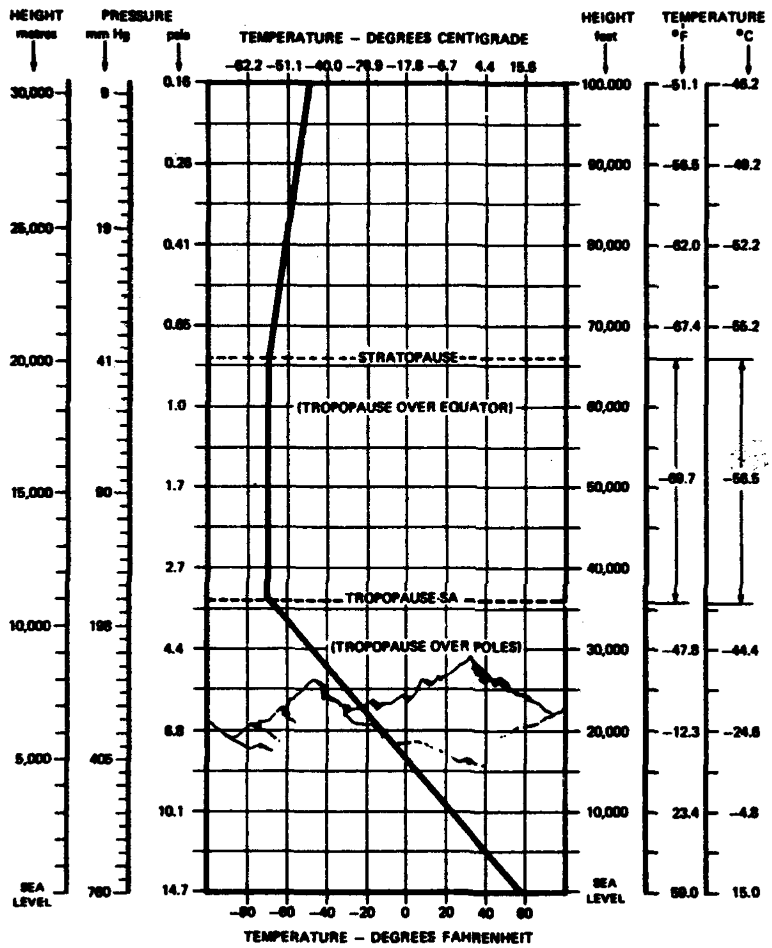
INTRODUCTION

1. The earth's atmosphere is the envelope of air which surrounds it and is composed of a mixture of gases. The atmosphere can be divided into four layers and the only feature which these have in common is that the atmospheric pressure decreases with increasing altitude. The important characteristics of the atmosphere are its composition, pressure, temperature and radiations.

LAYERS OF THE ATMOSPHERE

2. The layer which lies in contact with the earth's surface is the TROPOSPHERE, which is characterised by the presence of water vapour, a constant decrease in temperature with increasing altitude, and large scale vertical currents which keep its gaseous component remarkably constant. The troposphere extends from sea level to a height which varies from an average of 9 000m (30,000ft) at the poles, to about 18 000m (60,000ft) above the equator. These differences in height are due to the varying angles at which the sun strikes the surface of the earth and the greater amount of heat which is radiated from the earth's surface at the equator. The outer boundary of the troposphere is known as the TROPOPAUSE which, at a latitude of 40°N, lies at about 11 000m (36,000ft) and the conditions at that latitude are used to define the characteristics of the standard atmosphere in Fig.1.

3. The layer above the troposphere is the STRATOSPHERE which is about 14 000m (46,000ft) deep. It differs from the troposphere in that it has a constant temperature of −56.5°C (−69.7°F), due to a balance between the amount of direct heat from the sun which is absorbed by the atmosphere and the heat which is radiated into the atmosphere from the earth's surface. The upper boundary of the STRATOSPHERE is known as the STRATOPAUSE.



A diagrammatical representation of the properties of the standard atmosphere showing the variation in the height of the tropopause at different latitudes.

Fig. 1 Standard Atmosphere Chart

4. The third layer is known as the MESOSPHERE in which the temperature first rises and then falls to a minimum temperature of about −107°C (−162°F) at an altitude of around 80 km (50 miles).

5. The fringe of the mesosphere is known as the MESOPAUSE and it marks the beginning of the THERMOSPHERE which gradually becomes the vacuum of space. In this layer, the temperature increases again but there are so few particles of matter in the atmosphere at this height that temperature in the sense in which we know it has little meaning.

6. In some classifications of the upper atmosphere, the stratosphere is extended to a height of 80 km (50 miles), to include the mesosphere. From 80 km (50 miles) to 480 km (300 miles) is then known as the IONOSPHERE and from that height into deep space is known as the EXOSPHERE. The ionosphere is a region in which ionisation is intense and, in particular, produces important effects on radio communication. The exosphere is the outer boundary of the atmosphere.

COMPOSITION OF THE ATMOSPHERE

7. The composition, by volume, of dry air is:

Nitrogen (N_2)	78%
Oxygen (O_2)	21%
Carbon Dioxide (CO_2)	0.03%
Other inert Gases (Argon etc)	0.97%

(although the air throughout the troposphere contains variable quantities of water vapour, in relation to the temperature and degree of saturation, it is not considered as one of the components of the atmosphere in this context).

8. The gases which are of primary importance are oxygen and nitrogen, not only because they make up practically the whole of the atmospheric gas mixture but also because the others are not involved in the physiology of respiration and the effects of increasing altitude on man. For all practical

purposes, therefore, atmospheric air can be said to consist of 79% nitrogen and 21% oxygen and due to the efficient mixing of the air by atmospheric turbulence, these relative percentages remain unchanged, at least up to heights of many kilometres above the tropopause. The pressure of the atmospheric air falls with increasing height above sea level and it is this decrease in pressure which is fundamentally important to the aviator.

ATMOSPHERIC PRESSURE AND ALTITUDE

9. The barometric (atmospheric) pressure is equal to the weight of all the molecules of air above the point at which the measurement is made. This pressure decreases therefore with altitude, but the pressure drop is not linear since air is compressible. For this reason, the air near the surface of the earth becomes denser than that higher up, which means that there is a greater pressure change, for a given amount of height, nearer ground level.

10. The relationship between pressure drop and altitude is logarithmic; the atmospheric pressure is already reduced to half its sea-level value at a height of 5 500m (18,000ft). A rise from sea-level to 500m (1,500ft) results in a pressure drop of 44mm Hg, whereas, during a 500m (1,500ft) change in altitude from 4 000m (13,120ft) to 4 500m (14,760ft), that same height difference produces a pressure change of only 29mm Hg. At much higher altitudes this is even more marked; between 14 000m (45,930ft) and 14 500m (47,570ft) that same height band now represents a pressure difference of only 8mm Hg.

TEMPERATURE AND ALTITUDE

11. Solar radiation heats the earth's surface, which in turn re-radiates the heat to the atmospheric air. From the surface of the earth the temperature of the air falls steadily with altitude throughout the troposphere and this 'lapse rate' is 1.98°C (3.56°F) per 305m (1,000ft). Since the tropopause is always higher over the equator than over the poles, the application of a standard temperature lapse rate results in lower atmospheric temperatures in the stratosphere over the

TABLE 1

STANDARD ATMOSPHERE
ALTITUDE/BAROMETRIC PRESSURE/TEMPERATURE TABLES

Based on height in METRES

ALTITUDE		PRESSURE		TEMPERATURE	
Metres	feet	mmHg	psia	°C	°F
Sea level		760	14.7	15.0	59.0
400	1312	725	14.0	12.4	54.4
600	1968	707	13.7	11.1	52.0
800	2625	691	13.4	9.8	49.6
1000	3281	674	13.0	8.5	47.3
1500	4921	634	12.3	5.3	41.5
2000	6562	596	11.5	2.0	35.5
2500	8202	560	10.8	– 1.2	29.7
3000	9842	526	10.2	– 4.5	23.9
3500	11483	493	9.5	– 7.7	18.1
4000	13123	462	8.9	–11.0	12.2
4500	14764	433	8.4	–14.2	6.4
5000	16404	405	7.8	–17.5	0.5
5500	18044	379	7.3	–20.7	– 5.3
6000	19685	354	6.8	–24.0	–11.2
6500	21325	331	6.4	–27.2	–16.9
7000	22966	308	6.0	–30.5	–22.9
7500	24606	287	5.6	–33.7	–28.6
8000	26246	267	5.2	–36.9	–34.5
10000	32808	199	3.8	–49.9	–57.8
12000	39370	146	2.8	–56.5	–69.7
14000	45931	106	2.0	–56.5	–69.7
16000	52493	78	1.5	–56.5	–69.7
18000	59054	57	1.1	–56.5	–69.7
20000	65616	41	0.80	–56.5	–69.7
25000	82020	19	0.37	–51.6	–60.9
30000	98424	9	0.17	–46.6	–51.9

Note: 1 metre = 3.2808 feet; 1 foot = 0.3048 metres
1 mmHg = 0.0193 psi; 1 psi = 51.715 mmHg
T°C = 0.556 (T°F – 32); T°F = 1.8 T°C + 32
1 mmHg = 1 torr

TABLE 1

STANDARD ATMOSPHERE
ALTITUDE/BAROMETRIC PRESSURE/TEMPERATURE TABLES

Based on height in FEET

ALTITUDE		PRESSURE		TEMPERATURE	
feet	Metres	mmHg	psia	°C	°F
Sea level		760	14.7	15.0	59.0
1000	305	733	14.2	13.0	55.4
2000	610	707	13.7	11.0	51.9
3000	914	681	13.2	9.1	48.3
4000	1219	656	12.7	7.1	44.7
5000	1524	632	12.2	5.1	41.2
6000	1829	609	11.8	3.1	37.6
7000	2134	586	11.3	1.1	34.0
8000	2438	565	10.9	– 0.8	30.5
9000	2743	543	10.5	– 2.8	26.9
10000	3048	523	10.1	– 4.8	23.4
12000	3658	483	9.3	– 8.8	16.2
14000	4267	447	8.6	–12.7	9.1
16000	4877	412	8.0	–16.7	2.0
18000	5486	380	7.3	–20.6	– 5.1
20000	6096	350	6.8	–24.6	–12.3
25000	7620	282	5.5	–34.5	–30.0
30000	9144	226	4.4	–44.4	–47.8
35000	10668	179	3.5	–54.2	–65.6
40000	12192	141	2.7	–56.5	–69.7
45000	13716	112	2.1	–56.5	–69.7
50000	15240	87	1.7	–56.5	–69.7
55000	16764	69	1.3	–56.5	–69.7
60000	18288	54	1.0	–56.5	–69.7
70000	21336	34	0.65	–55.2	–67.4
85000	25908	16	0.32	–50.7	–59.3
100000	30480	8	0.16	–46.2	–51.1

Note: 1 metre = 3.2808 feet — 1 foot = 0.3048 metres
1 mmHg = 0.0193 psi — 1 psi = 51.715 mmHg
T°C = 0.556 (T°F – 32) — T°F = 1.8 T°C + 32
1 mmHg = 1 torr

equator. These temperatures also vary according to the time of the year, since the tropopause is higher in the summer than in the winter.

INTERNATIONAL STANDARD ATMOSPHERE

12. The International Standard Atmosphere (Fig.1 and Table 1) is derived from average conditions in temperate latitudes (latitude 40° in N. America) and provides a uniform description of the atmosphere as a basis for comparison. The characteristics on which the Standard Atmosphere have been based are as follows:–

(a) Sea-level pressure: 760mm Hg, or 14.7 psi, or 1013 millibars or 29.9 in Hg.

(b) Sea-level temperature: 15°C (59°F).

(c) Adiabatic lapse rate in the troposphere: 1.98°C (3.56°F) per 305m (1,000ft).

(d) Height of tropopause: 11 000m (36,000ft).

PHYSICAL CHARACTERISTICS OF ATMOSPHERIC GASES

13. In order to understand the various effects of changing altitude in the human body, it is important to bear in mind the essential physical laws which concern these gases.

(a) BOYLE-MARRIOTTE'S LAW (also known as BOYLE'S LAW) states that, at constant temperature, the volume of a gas varies inversely with the pressure. If the pressure of gas is halved, its volume is doubled. This law relates to dry gas however, and gases in the body are saturated with water vapour (see Chapter 3, paragraph 10). This modifies the (PV = constant) relationship and for a given pressure ratio, the greater the altitude the greater the gas expansion (see Chapter 7, paragraph 3).

(b) DALTON'S LAW (of partial pressures) states that the partial pressure of a gas in a gas mixture is equal to that pressure which this gas would exert if it alone occupied the space taken up by the mixture. Each of the gaseous components in a mixture exerts a pressure

that is proportional to the fraction which it represents of the total gas mixture; this, in turn, corresponds to its percentage volume. (For example, 21% oxygen in atmospheric air represents a fraction of 0.21). The 'total pressure' of a gas mixture is, therefore, the sum of the pressures of the individual gases in the mixture. The partial pressure of a given gas (say X) can be obtained from the formula:

$$P_X = P_B.F,$$

where, P_X = partial pressure of gas X

P_B = total barometric pressure

F = fractional concentration of gas X

In the case of oxygen (21%), in a sample of dry atmospheric air, at a standard sea-level pressure of 760mm Hg:

$$PO_2 = 760 \times 0.21$$
$$= 159.6\text{mm Hg}$$

i.e. the partial pressure of oxygen (PO_2) in dry atmospheric air is approximately 160mm Hg.

(c) CHARLES'S LAW indicates that when temperature increases and the pressure is maintained constant, gases expand according to the following relationship:

$$V_t = V_o (1 + \alpha t),$$

where, V_t = the gas volume at temperature t,

V_o = the gas volume at 0°C,

α = the coefficient of expansion of gases at constant pressure and is equal to 1/273,

t = the gas temperature in °C.

(d) A combination of BOYLE'S LAW and CHARLES'S LAW gives the following relationship between the volume, temperature and pressure of a gas:

$$PV = nRT$$

where, P = Pressure of the gas

V = Volume of the gas

n = Number of chemical units of gas present

R = a constant

T = the absolute temperature in degrees Kelvin (ie the temperature in °C + 273°)

This relationship shows that if volume (V) remains constant, the pressure exerted by a gas (P) varies directly with the absolute temperature (T) which is measured by °C plus 273°.

(e) HENRY'S LAW states that the quantity of gas that goes into solution, at a given temperature, is dependent upon its solubility characteristics and is proportional to the partial pressure of that gas over the surface of the liquid. Hence as the pressure falls, the amount of gas which can be held in solution is reduced. The application of this will be discussed in the chapter dealing with the effects of decreased barometric pressure (see Chapter 6).

IONISING RADIATION

14. Ionising radiation is the name for the type of radiation which comes from such sources as the hospital X-ray apparatus, nuclear weapons and cosmic rays and can, in sufficient quantities, damage human tissue by ionising atoms within the tissue cells.

15. The intensity of cosmic radiation varies at different altitudes and geographical locations. When the primary cosmic rays enter the earth's atmosphere they collide with air molecules and by virtue of their high energy produce a wide variety of secondary radiation. The maximum intensity of cosmic rays occurs between 18 000m (60,000ft) and 36 000m (120,000ft). It is in this zone of absorption that they lose their original form and the energetic primary cosmic particles produce a shower of secondary cosmic rays

which fall towards the earth's surface. The intensity of this radiation diminishes rapidly with decreasing altitude since it is absorbed by the atmospheric gases and to a lesser extent, by precipitation and dust in the atmosphere so that at sea level the radiation is only abo one seventieth of the intensity at 21 000m (70,000ft).

16. In terms of current aircraft operating in the high altitude role, the amount of radiation which crews receive is very small and does not present a hazard. For example, it has been calculated that if an aviator were to spend 1,000 hours per year at a height of 17 000m (55,000ft) the radiation dose rate per week would still only be half the amount considered safe for industrial workers continuously exposed.

17. Ozone is triatomic oxygen (O_3) and is formed by the shorter range of ultra-violet rays from solar radiation being absorbed by oxygen (see Chapter 15). Most of the ozone is formed at altitudes between 15 000 and 40 000 metres (50,000–140,000ft), the maximal concentration being at about 23 000m (75,000ft). Ozone is highly toxic when inhaled, even in small quantities; it is also very destructive to rubber. Fortunately, however, it is unstable and in particular, it is rapidly dissociated by heat into O_2, the dissociation being virtually instantaneous at about 300°C (572°F). It is, therefore, largely destroyed as it passes through the engine compressors and since the air which pressurises the cabin of jet aircraft comes from this source, ozone is not a significant hazard to the aviator.

- **ATMOSPHERIC AIR IS ROUGHLY 21% O_2 AND 79% N_2.**
- **DECREASE IN ATMOSPHERIC PRESSURE WITH INCREASING ALTITUDE IS LOGARITHMIC.**
- **TEMPERATURE LAPSE RATE IS ABOUT 2°C (3.6°F) PER 300m (1,000FT).**
- **COSMIC RADIATION DOES NOT PRESENT A HAZARD TO THE AVIATOR.**
- **OZONE IS NOT A SIGNIFICANT HAZARD TO THE AVIATOR.**

CHAPTER 3

RESPIRATION AND CIRCULATION

INTRODUCTION

1. Respiration is the process by which a living organism exchanges gases with its environment; and the circulation is the transport system whereby the blood carries oxygen and nutriment to the tissues and removes waste products. These two functions are closely inter-related and the human body depends upon their efficiency for the maintenance of life and health.

2. The tissue cells need a continuous supply of oxygen for the complicated chemical reactions which convert food elements into the energy necessary for life. The body is unable to store oxygen and certain tissue cells are particularly susceptible to a shortage of oxygen. For example, if the supply of oxygen to the brain were cut off completely, the brain cells would cease to function within a matter of seconds and cell death would soon follow. The metabolic process, whereby nutriment is converted into energy, also gives off many by-products which must be removed from the body. Carbon dioxide, one of these, is transported back to the lungs by the circulation and exhaled as part of the process of respiration.

RESPIRATION

3. The lungs, which communicate freely with the environment, lie in the thoracic cavity which is bounded by the rib cage and the diaphragm (see Fig.2). The thorax is a closed cavity, so that any change in its volume causes the volume of the lungs to change. The potential space between the lungs and chest wall is known as the pleural cavity.

4. During inspiration, the volume of the thorax is increased by contracting the diaphragm and elevating the ribs. Since the diaphragm consists of a dome-shaped sheet of muscle extending upwards into the chest, the act of contraction tends

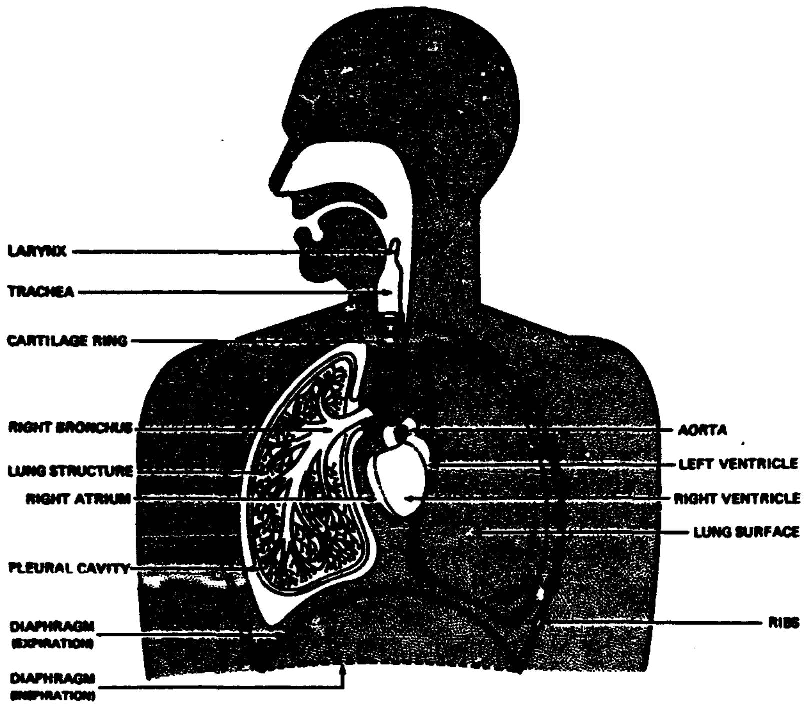


Fig.2 The Respiratory System

to flatten the diaphragm and therefore lower it. These combined actions of the ribs and diaphragm increase both the cross-sectional and longitundinal volume of the chest; drawing air into the lungs.

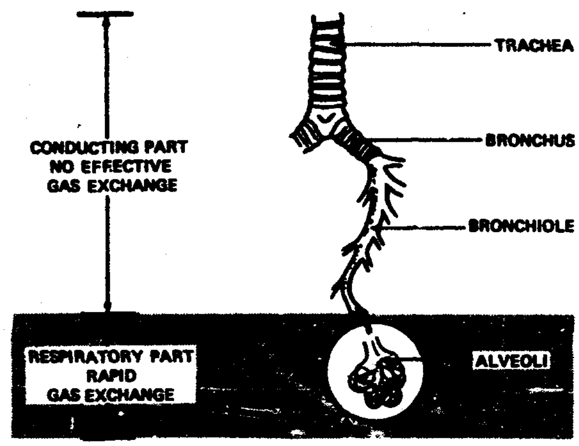
5. Expiration is the passive phase of respiration during which the already inflated lungs relax. It is triggered off by the inhibition of nerve impulses which stimulate inspiration whilst the lungs are still inflated, so that they return to their resting size. Under conditions of strenuous exercise, an active component exists since accessory respiratory muscles in the chest wall contract to compress the chest.

6. The rate and depth of breathing are controlled by the metabolic demands of the tissues; when the tissues need more oxygen to convert nutriment into energy, breathing increases. The gas side of the alveolar membrane is only one part of the functional unit and the blood flow through the lungs must also increase in these circumstances if effective gas exchange is to take place.

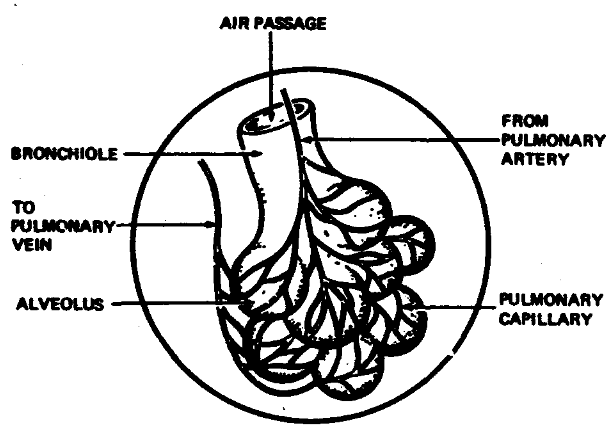
7. From the functional point of view, the respiratory tract can be divided into two parts, conducting and respiratory, (see Fig.3a):

(a) THE CONDUCTING PART – This consists of the various passageways through which the lung gas communicates with the environment; namely the mouth, nose, larynx (voice-box), trachea (wind-pipe), ramifications within the lungs known as the bronchi and the conducting bronchioles (smaller bronchi). The significant feature of the conducting system is that it plays no direct part in the transfer of oxygen and carbon dioxide between the lung gas and the blood. Its function, apart from acting as an air passage, is to warm, humidify and filter the incoming air.

(b) THE RESPIRATORY PART – This consists of the smaller, so-called respiratory bronchioles, alveolar ducts and alveoli. At the end of each respiratory bronchiole, the tube opens out into an irregular air-sac which has been likened to a bunch of grapes, each grape representing an alveolus. Individual air-sacs are very small indeed and are barely discernable to the naked eye. Small blood capillaries are distributed in the walls of every respiratory bronchiole and alveolus and each minute air-sac/capillary complex represents the functional unit of the lung which is responsible for the exchange of oxygen and carbon dioxide. It is, therefore, the actual place at which gas exchange takes place (see Fig.3b). There are a great many such minute units; indeed the total area of the alveolar walls is about $95 m^2$ (1,000 sq ft). Diffusion of gas takes place across the microscopically thin alveolar membrane almost instantaneously; oxygen passing from the lung gas into the blood and carbon dioxide diffusing out to be exhaled.



(a) This shows the anatomical subdivision of the respiratory tract into the conducting and respiratory parts.



(b) The alveolus is the functional unit of the lung in which gas exchange with the blood takes place.

Fig.3 The Respiratory Tract

8. The fundamental factor which regulates breathing is the partial pressure of carbon dioxide (PCO_2) within the respiratory centre in the brain. It is extremely sensitive to small changes in the carbon dioxide tension of the blood and continuously adjusts the breathing pattern to maintain this tension at the normal level.

COMPOSITION OF ALVEOLAR AIR

9. Oxygen is constantly diffusing from the gas mixture in the alveoli into the blood and carbon dioxide across the alveolar membrane in the opposite direction so that the composition of alveolar air is quite different from atmospheric air (see Fig.4). The composition of dry alveolar air is approximately:

Oxygen (O_2)	=	14.5%
Nitrogen (N_2)	=	80.0%
Carbon Dioxide (CO_2)	=	5.5%

10. The factor which influences the diffusion of gas across the alveolar membrane is the partial pressure of the gas, which can be obtained from the formula:

$$P_X = P_B . F,$$

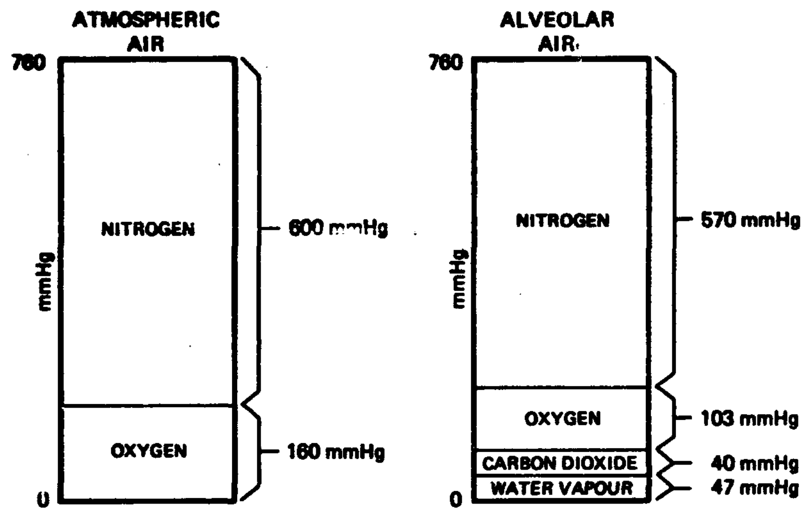
as explained in paragraph 13b of the previous chapter. Before calculating the partial pressure of the alveolar gases, however, a further factor must be taken into consideration. Alveolar air is always completely saturated with water vapour which exerts its own partial pressure of 47mm Hg, at deep body temperature, irrespective of altitude. This means that 47mm must be subtracted from the total gas pressure before the partial pressures of the other alveolar gases can be calculated. The partial pressure of oxygen in the lungs (PAO_2) at a standard sea-level pressure of 760mm Hg can therefore be calculated as follows:–

$$\begin{aligned} PAO_2 &= (P_B - 47) \times F, \\ &= (760 - 47) \times 0.145 \\ &= 103\text{mm Hg} \end{aligned}$$

where: PAO_2 = partial pressure of oxygen in the alveolar air

P_B = barometric pressure

F = fractional concentration of oxygen in dry alveolar air.



This figure shows the significant difference between atmospheric air and alveolar gas, namely the presence of carbon dioxide and water vapour in the lungs.

Fig.4 Atmospheric Air and Alveolar Gas

11. The partial pressure of oxygen in the alveolar air is 103mm Hg and in the partly deoxygenated venous blood on the other side of the alveolar membrane is only 40mm Hg, so there is an oxygen pressure difference of 63mm Hg across the membrane. Since gases diffuse from an area of high pressure to one of lower pressure, the oxygen diffuses from the gas to the blood side of the alveolar membrane. In the case of carbon dioxide, there is a pressure gradient of some 6mm Hg in the reverse direction, so carbon dioxide diffuses

out of the blood into the alveolar air. Finally, the gas partial pressures in the blood at the end of the pulmonary capillary are in equilibrium with the gas pressures in the alveolar gas.

CIRCULATION

12. The circulatory system is the means whereby the blood transports oxygen and carbon dioxide to and from the tissue cells. It also carries nutrients to the tissues and removes waste products to the appropriate disposal sites, namely the lungs, kidney, liver and sweat glands.

13. The circulatory system consists of the heart, arteries, veins and capillaries and is shown diagramatically in Fig.5. The heart is the pump which maintains the circulation, the arteries and veins are the main conducting vessels which carry the oxygenated blood to, and venous blood from, the

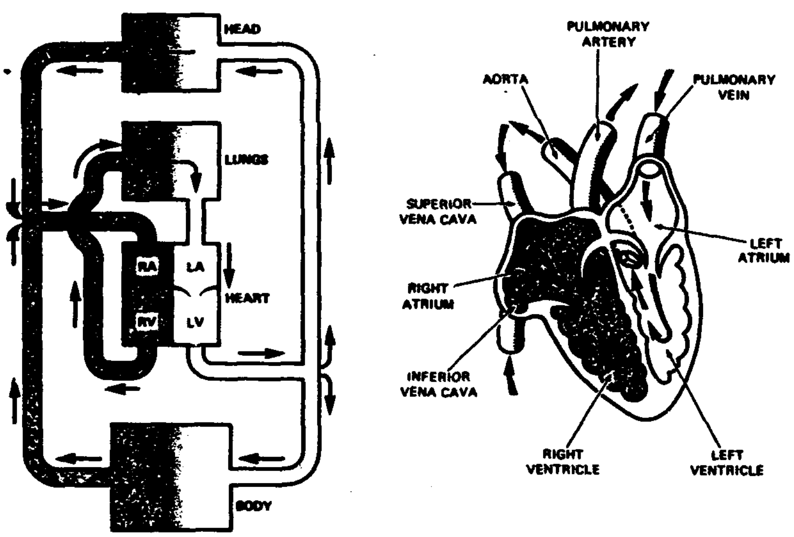


Fig.5 The Circulatory System

tissues. The capillaries are small vessels which connect the arteries and veins, through whose thin walls the gas and nutrient exchange takes place with the tissues.

14. The blood is propelled round the circulation by the contraction of the heart. When the ventricles contract they exert a force on the blood in the main artery leaving the heart (aorta) which produces enough pressure to drive the blood through the arterial side of the circulation into the capillaries. The ventricular contraction produces an arterial blood pressure of about 120mm Hg which stretches the arteries. When the ventricles of the heart relax, the contraction of the distended arterial walls exerts enough force on the blood to maintain a relatively high pressure in the arterial blood of about 70mm Hg. Thus the blood pressure is described by two figures e.g. (120/70); this is not a fixed value and quite wide variations occur within normal limits. The blood pressure in the veins on the return side of the circulation is very much lower and indeed, venous return to the heart depends very largely on the squeezing action of the skeletal muscles forcing blood along the veins; the heartward direction being determined by the direction of the non-return valves within the veins.

CARRIAGE OF OXYGEN

15. It was pointed out in paragraph 11 that oxygen diffuses from the gas to the blood side of the alveolar membrane and by this means it enters the liquid part of the blood (plasma), so that finally the oxygen tension in the arterialised blood emerging from the pulmonary capillary is equal to that in the alveolar gas. However, after the oxygen has diffused into the bloodstream, only a minute fraction of it is carried round the body in simple solution, nearly all of it circulates in combination with the haemoglobin in the red cells of the blood. Haemoglobin (Hb) has a considerable affinity for oxygen and reacts with it to form oxyhaemoglobin (HbO_2) according to the reaction,

$$Hb + O_2 \rightleftharpoons HbO_2,$$

where Hb denotes non-oxygenated haemoglobin. The amount of oxygen which will combine with haemoglobin is regulated

by the tension of oxygen in the alveoli (PAO_2) and so the aviator can relate the state of oxygenation of the tissues to the tension of oxygen in the inspired air (see Fig.6, Chapter 4), even though the relationship is not linear (see Chapter 4, Fig.7). This S-shaped curve shows that the Hb is more or less completely saturated (over 90%) when the PO_2 is over 60mm Hg, whereas the HbO_2 combination drops rapidly as the pressure decreases below that figure. The relationship between haemoglobin and oxygen is also readily reversible, an essential characteristic which ensures that oxygen is unloaded from the blood to the tissue cells.

CONCLUSION

16. The respiratory and circulatory systems are well matched and interrelated; together they respond quickly and efficiently to the body's needs, thus ensuring that the tissue cells receive the oxygen and nutrients they require to carry out their essential functions and, at the same time, take care of the waste products which are produced. The amount and rate of gas transfer are determined significantly by the partial pressures of the oxygen and the carbon dioxide.

- **BREATHING IS REGULATED BY THE PCO_2 IN THE RESPIRATORY CENTRE OF THE BRAIN.**
- **RESPIRATORY GAS EXCHANGE TAKES PLACE AT THE ALVEOLAR MEMBRANE.**
- **AMOUNT AND RATE OF GAS TRANSFER DETERMINED BY GAS PARTIAL PRESSURES.**
- **ALVEOLAR GAS PRESSURES ARE IN EQUILIBRIUM WITH PULMONARY CAPILLARY PRESSURES.**
- **THE VENTRICLES DRIVE THE ARTERIAL BLOOD TOWARDS THE CAPILLARIES.**
- **VENOUS RETURN DEPENDS UPON THE SQUEEZING ACTION OF SKELETAL MUSCLES.**

CHAPTER 4

EFFECTS OF DECREASED PARTIAL PRESSURE OF OXYGEN

INTRODUCTION

1. The importance of this subject cannot be over-emphasised since the effects of oxygen lack (hypoxia) have been the cause of many aircraft accidents. These accidents are not always caused by a major oxygen system failure at very high altitude; many arise from aircrew errors due to mild hypoxia which has not been appreciated by the crew-member.

HYPOXIA (ANOXIA)

2. Hypoxia denotes a situation in which the supply of oxygen to the tissue cells is insufficient to prevent impairment of function. Many use the term 'anoxia' to define this state but the more accurate term, 'hypoxia', meaning an inadequate supply of oxygen, rather than a total lack of oxygen, is used in this text. A deficiency of oxygen can occur in many different ways but to the aviator the most important cause is a reduction in the partial pressure of oxygen in the inspired air.

3. In aviation, oxygen lack represents a condition of extreme hazard. It is aggravated by the fact that a mild degree of hypoxia, not fatal in itself, may have fatal results through causing a critical deterioration in aircrew performance.

4. It is difficult to say at what altitude the human body becomes hypoxic. The threshold of hypoxia could be considered to be as low as 1 000 m (3,300 ft) since no demonstrable physiological reaction to decreased atmospheric pressure has been reported below that height. In practice, however, a significant decrement in performance does not occur as low as that, but as altitude increases above that level the first symptoms of hypoxia begin to appear (see paragraph 13) and a more realistic threshold would be around 1 500 m (5,000 ft). Oxygen systems are, however, commonly

designed to provide a partial pressure of oxygen in the inspired air equivalent to ground level conditions, at least up to an aircraft altitude of 10 000 m (33,000 ft).

CAUSES OF HYPOXIA

5. The cause of hypoxia has already been given in paragraph 2, namely a decrease in the partial pressure of the inspired oxygen (PIO_2) and it is therefore useful to calculate the PIO_2, for sea-level conditions, as a base line. Since the inspiratory gas becomes saturated with water vapour as it passes down the respiratory passages, the formula which is used for the calculation must take into account the fact that the gas is wet: $PIO_2 = (P_B - P_{wv}) \times P$, (where P_{wv} is the water vapour pressure at deep body temperature), so the calculation is as follows:

$$PIO_2 = (760-47) \times 0.21,$$
$$= 150\text{mm Hg}$$

where PIO_2 = partial pressure of oxygen in the inspired air

760 = sea-level barometric pressure (mm Hg)

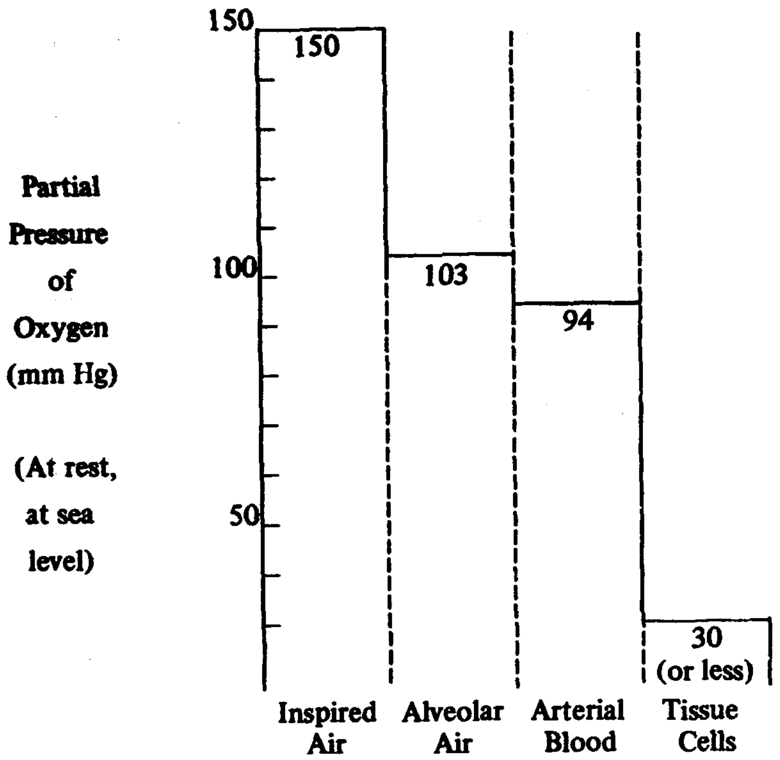
47 = water vapour pressure at body temperature (mm Hg)

0.21 = fractional concentration of oxygen in inspired air

(as explained in Chapter 3, paragraph 10)

The PIO_2 at sea-level is 150mm Hg and at 1 500 m (5,000 ft), where the barometric pressure is 634mm Hg, the PIO_2 is 123mm Hg. The latter is therefore the PIO_2 associated with the threshold of hypoxia, but ideally oxygen systems aim at maintaining a PIO_2 of 150mm Hg.

6. The effect of decreasing the partial pressure of the oxygen in the inspired air is to diminish the oxygen tension in the alveoli; reducing the concentration of oxygen in the alveolar capillary blood. Fig.6 shows the various stages in the transfer of oxygen by diffusion from the inspired air to the tissue cells. This process depends upon the gas tension gradients at each stage and if the tension is diminished at the



The transfer of oxygen from the inspired air to the tissues depends upon an adequate level of gas tension at each stage or the tissue cells become hypoxic.

Fig.6 Transfer of Oxygen to the Tissues

input, this is reflected throughout and the partial pressure of oxygen in the tissue cells is correspondingly reduced thereby producing the primary effects of hypoxia. Adequate oxygenation of the tissue cells therefore depends upon maintaining a satisfactory partial pressure of oxygen in the inspired air.

7. It has already been pointed out in Chapter 3, paragraph 15 that the relationship between the partial pressure of

oxygen and the amount of oxygen which is carried by the blood as oxyhaemoglobin is not linear, (see also Fig.7). For aircrew, the significance of this curve being S-shaped is that the oxygen tension falls much more rapidly at altitudes above 3 000 m (10,000 ft) than if the relationship had been linear.

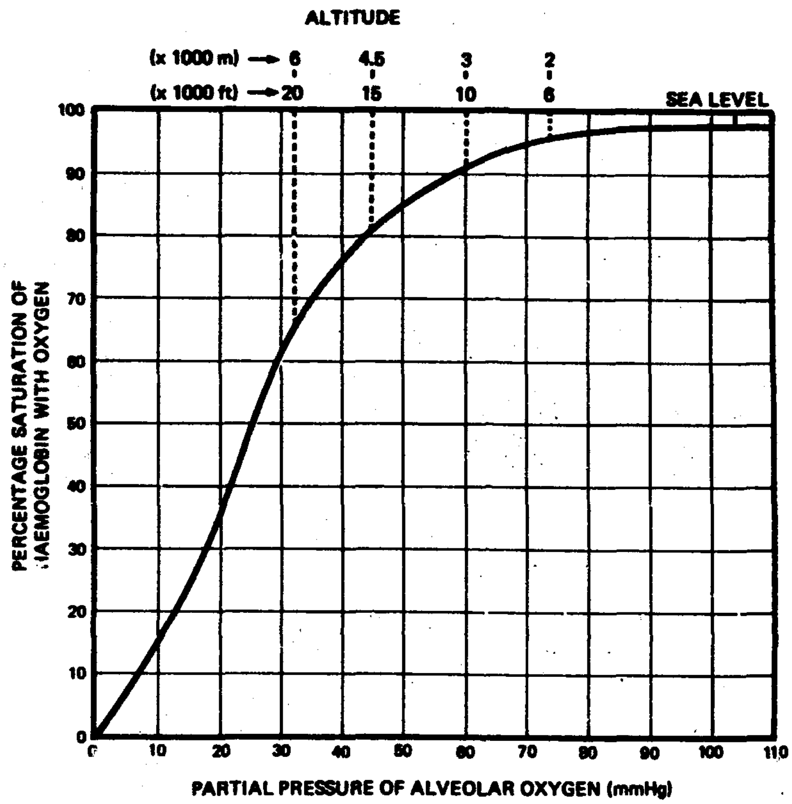
8. In summary, the partial pressure of oxygen entering the respiratory passages dictates whether or not the tissue cells suffer from hypoxia and the methods of protection which are described in the next chapter are based on maintaining that partial pressure at an adequate level.

SYMPTOMS OF HYPOXIA

9. When the aviator is breathing atmospheric air, the severity of the symptoms of hypoxia depend primarily on the 'cabin altitude' and the time of exposure to that altitude.

10. In the early days of flying, aviators frequently experienced the classic symptoms of hypoxia, because ascents were made without breathing additional oxygen and were sufficiently slow to allow the full range of symptoms to occur before consciousness was lost. With a rapid rate of ascent to a high cabin altitude, unconsciousness can occur before many of the warning symptoms are appreciated. The body shows the effects of oxygen lack in a sequence which is dictated by the sensitivity of the different tissue cells to a reduction in oxygen tension. The brain cells are very sensitive to hypoxia and those areas of the brain associated with the powers of judgment, self-criticism and the accurate performance of mental tasks are adversely affected at relatively low altitudes.

11. For the times of exposure likely to be experienced by aircrew, altitude probably only becomes significant as a cause of hypoxia at heights above 1 500 m (5,000 ft). At altitudes above 3 000 m (10,000 ft), errors in judgment become apparent to an observer, but these errors are often not realized by the subject himself, since a lack of appreciation is one of the very real hazards of this condition. Indeed, an individual is likely to believe not only that he is in full possession of his faculties, but more seriously, that he is flying more accurately than usual. He is also likely to take an



This shows that oxygen tension falls rapidly above 3 000 m (10,000 ft). A similar situation arises above 10 000 m (33,000 ft), breathing pure oxygen, (see Chapter 5, paragraph 4).

Fig.7 Carriage of Oxygen in the Blood

occasional deep breath or yawn and vague feelings of apprehension and restlessness are common; sometimes associated with headache or dizziness.

12. At a later stage, or with exposure to a higher altitude, greater changes occur. The subject begins to tremble and become generally clumsy in his movements; questions or

instructions may be ignored and vision becomes affected. A pilot may fail to appreciate alterations in the attitude of his aircraft until they become quite marked and even then he may not make any attempt to carry out the appropriate corrective action. It is this failure to appreciate and to react to problems which can lead to loss of control of the aircraft with possibly fatal results. Changes in an individual's mood are common and may take the form of hilarity, pugnacity or drowsy apathy. Finally, consciousness is lost and the unsupported man collapses.

13. Individuals vary in their resistance to oxygen lack and the fact that one man can withstand certain conditions does not mean that others will react in the same way. The poor oxygenation of the blood in a hypoxic subject is particularly noticeable in the lips and nail beds which have a bluish tinge. In summary, the signs and symptoms of hypoxia are many and various and they differ from individual to individual; typical effects are as follows:

(a) Feeling of tiredness and sleepiness.
(b) Headache (particularly if mildly hypoxic for long period).
(c) Impaired judgment.
(d) Light-headedness and dizziness.
(e) Visual disturbances.
(f) Tingling in hands and feet.
(g) Loss of self-criticism.
(h) Dulling of thought, depression and perhaps nausea.
(j) Altered respiration.
(k) Euphoria with outbursts of hilarity.
(l) Pallor of skin, blueness of lips and finger nails.
(m) Effect on hearing – ambient noises become faint.
(n) Incoordination of limbs and disorientation.
(o) Semi-consciousness.
(p) Muscular spasm and convulsions.
(q) Unconsciousness.

FACTORS INFLUENCING TOLERANCE

14. There are a number of factors which increase an individual's susceptibility to hypoxia and aggravate mild hypoxia:

(a) ALTITUDE – Hypoxia occurs if an ascent is continued above 1 500 m (5,000 ft), when breathing air; or if the amount of oxygen added to the breathing mixture is inadequate to maintain the necessary partial pressure of oxygen in the inspired air at the particular altitude. As height increases, the time lapse between an oxygen system failure and loss of consciousness gets progressively shorter. The alveolar oxygen tension can be maintained at its sea-level value up to 10 000 m (33,000 ft) by increasing the proportion of oxygen in the inspired gas, but above this height it falls, even when pure oxygen is breathed. This drop in the alveolar oxygen tension at these very high cabin altitudes can only be prevented by maintaining the total alveolar gas pressure by artificial means such as positive pressure breathing, which will be discussed in the next chapter.

(b) FATIGUE – An individual who is mentally or physically fatigued tolerates hypoxia poorly since he is already bordering on performance decrement and the added factor of hypoxia tips the balance adversely.

(c) EXPOSURE TO EXTREMES OF TEMPERATURE – Extremes of heat or cold place a heavy demand upon the circulatory adjustments which the body has to make, and these lower tolerance to hypoxia.

(d) PHYSICAL EXERTION – Physical exertion increases the oxygen requirements of the tissue cells; so that for a given partial pressure of inspired oxygen an individual will be more hypoxic than he would be at rest. This means that the times of useful consciousness at a given altitude will be considerably shorter than if the subject were at rest.

(e) ALCOHOL OR ITS AFTER-EFFECTS – Alcohol has profound effects both on the circulation and the tissue cells which lower their tolerance to hypoxia. Alcohol also has significant effects on behaviour, producing depressant after-effects which aggravate the behavioural changes produced by hypoxia.

(f) SMOKING – Heavy smoking produces 8-10% carboxyhaemoglobin in the blood thereby reducing its oxygen carrying capacity to some extent and aggravating existing hypoxia (see Chapter 15).

(g) DRUGS – Stimulant or depressant drugs increase an individual's susceptibility to hypoxia because of the impairment of judgment they may create.

TIME OF USEFUL CONSCIOUSNESS

15. In the context of hypoxia in flight, the time of useful consciousness refers to the time available to an individual, after he has been deprived of his oxygen supply, during which he is still fully aware of his environment and is capable of controlling his aircraft safely. This time period varies both with altitude and between individuals; it is also shortened by physical exertion and these other factors which have already been discussed in paragraph 14. Table 2 gives examples of average times of useful consciousness at various altitudes. It must be stressed that these mean times are only a guide, and that in individual cases these times can vary quite markedly. The table nevertheless demonstrates that, at high altitude, the time of useful consciousness is short and when carrying out a skilled and energetic task, the time will be even shorter. Aircrew should not be misled into thinking that the times quoted in Table 2 are conservative because of experiences they may have had or witnessed in a decompression chamber. The air in a decompression chamber may be falsely enriched with oxygen from various sources and subjects are sitting quietly at rest in a non-stressful situation; these factors both materially increase the time of useful consciousness.

CONCLUSION

16. Decreased atmospheric pressure causes hypoxia by reducing the partial pressure of oxygen in the inspired air. This can lead to flying accidents because of the detrimental effects of the resultant hypoxia on an individual's performance. The prevention of hypoxia is the subject of the next chapter.

TABLE 2

TIME OF USEFUL CONSCIOUSNESS

ALTITUDE		RAPID DISCONNECT	
Metres	Feet	Moderate Activity	Sitting Quietly
6 500	21,000	5 minutes	10 minutes
7 500	25,000	2 minutes	3 minutes
8 500	28,000	1 minute	1½ minutes
9 000	30,000	45 seconds	1¼ minutes
10 500	35,000	30 seconds	45 seconds
12 000	40,000	18 seconds	30 seconds
20 000	66,000	12 seconds	12 seconds

Note: These are average values which can vary considerably according to the degree of skill which is involved in the particular task in question. In difficult circumstances, calling for complex decision making, the effective times of useful consciousness may be reduced.

- **HYPOXIA REPRESENTS EXTREME HAZARD TO THE AVIATOR.**
- **HYPOXIA IS DUE TO REDUCED TENSION OF OXYGEN IN THE TISSUES.**
- **THRESHOLD OF HYPOXIA IS AROUND 1 500 M (5,000 FT).**
- **LACK OF AWARENESS OF HYPOXIC STATE IS COMMON.**
- **TIMES OF USEFUL CONSCIOUSNESS MAY BE VERY SHORT.**
- **PREVENTION OF HYPOXIA IS BASED ON MAINTAINING PIO_2.**

CHAPTER 5

PREVENTION OF HYPOXIA

INTRODUCTION

1. Since hypoxia is caused by a lowering of the oxygen tension in the inspired air, it follows that its prevention is based on maintaining the partial pressure of oxygen in the inspired air as near to the ground level value as possible. Basically, there are two ways of doing this:

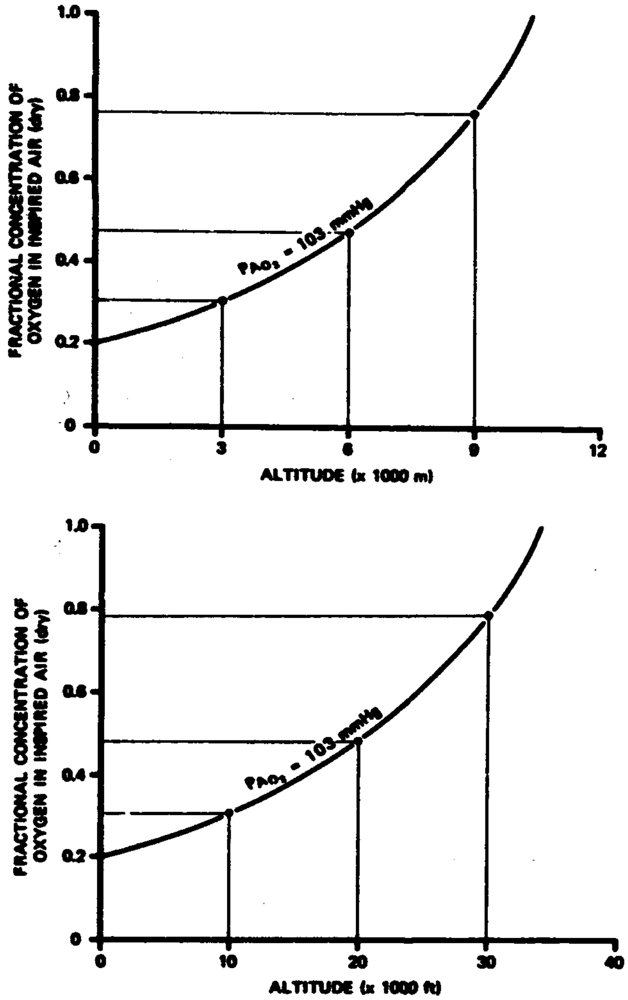
(a) By keeping the pressure in the aircraft cabin at or near ground level.

(b) By increasing the proportion of oxygen in the inspired gas mixture as altitude increases.

2. In modern military aircraft, both methods of preventing hypoxia are usually available. The pressure cabin is discussed in Chapter 8, however, so the remarks which follow will be confined to the use of oxygen systems and any reference to altitude or atmospheric pressure will relate solely to the conditions immediately surrounding the body.

USE OF OXYGEN IN FLIGHT

3. Although it was shown in the previous chapter that 1 500 m (5,000 ft) was the approximate threshold altitude for the onset of hypoxia, aircraft oxygen systems are commonly designed to supply automatically an increasing proportion of oxygen to the inspired gas mixture, which is sufficient to maintain sea-level conditions. This ensures an increased margin of safety in the event of an oxygen mask leak. Under sea-level conditions, the tension of oxygen in the alveolar air is 103mm Hg (see Chapter 3, paragraph 10) and this value can be maintained (up to a height of 10 000 m (33,000 ft) by adding sufficient oxygen to the inspired air mixture as altitude increases. The fractional concentration of oxygen in the inspired air (FIO_2) which is required to maintain this alveolar oxygen tension (PAO_2) of 103mm Hg from ground level to 10 000 m (33,000 ft) is shown in Fig.8.



As altitude increases, the fractional concentration of oxygen in the inspired air must be increased by the amount shown, in order to maintain an oxygen tension in the alveolar air (PAO_2) equivalent to ground level conditions.

Fig.8 Proportion of Oxygen in Inspired Gas (shown in metres and feet)

4. Above 10 000 m (33,000 ft), as the atmospheric pressure continues to fall with increasing altitude, the partial pressure of oxygen in the inspired air also begins to fall, even when breathing 100% oxygen. During an ascent from 10 000 m (33,000 ft) to 12 000 m (40,000 ft), breathing 100% oxygen, the alveolar oxygen tension more or less repeats the decline which occurs between sea level and 3 000 m (10,000 ft), breathing air. From the point of view of the oxygen supply, therefore, breathing 100% oxygen at 12 000 m (40,000 ft), is equivalent to breathing air at 3 000 m (10,000 ft). At that height, therefore, the alveolar oxygen tension is less than the desirable sea level value, but the degree of performance decrement due to hypoxia is sufficiently small to be acceptable for a considerable period of time. Modern high altitude aircraft are pressurised (see Chapter 8) so that crew members will only be exposed to the low atmospheric pressure at this height if the pressure cabin fails in an emergency situation. If efficiency is to be maintained for more than a very short time above 12 000 m (40,000 ft) breathing 100% oxygen at ambient atmospheric pressure is not sufficient, however, since the partial pressure of oxygen in the lungs will have fallen below the critical value (PAO_2 = 60mm Hg), which is necessary to maintain an adequate supply of oxygen to the tissue cells. Above 12 000 m (40,000 ft), therefore, the supply of 100% oxygen must be provided at a pressure greater than atmospheric. This is called 'positive pressure breathing' and it is achieved by means of special pressure breathing oxygen regulators and personal breathing assemblies, (see Chapter 19).

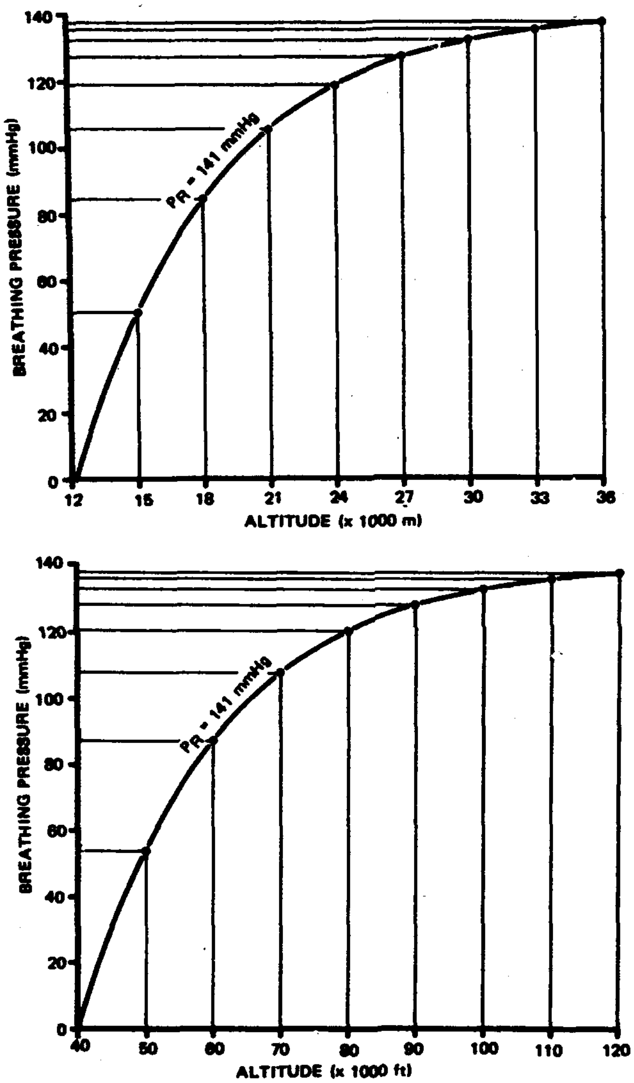
PHYSIOLOGY OF POSITIVE PRESSURE BREATHING

5. The underlying principle behind the majority of positive pressure breathing assemblies is to maintain a satisfactory partial pressure of oxygen in the inspired gas mixture, irrespective of the actual altitude around the man. This usually involves supplying 100% oxygen at a positive pressure which is sufficient to provide a so-called 'lung equivalent' in the region of 12 000 m (40,000 ft). In other words, the oxygen is supplied at a pressure equal to the difference between the atmospheric pressure at the altitude of exposure and the

atmospheric pressure at 12 000 m (40,000 ft) (see Fig.9). The oxygen tension in the inspired gas is thereby maintained at a level which is adequate for a short period of exposure, since from the oxygen point of view, breathing 100% oxygen at that height is equivalent to breathing air at 3 000 m (10,000 ft). Certain air forces (e.g. USAF) design oxygen regulators which supply pressure breathing, plus 100% oxygen, from a height of 10 500 m (35,000 ft) and make that the practical pressure altitude at which to begin pressure breathing. Aircrew will appreciate that there is a need to specify altitudes above which pressure breathing is mandatory, because of the fairly critical conditions which can occur around 12 000 m (40,000 ft). This is particularly important if exposure times are likely to be extended since these calculations depend upon the supply of 100% oxygen (i.e. no dilution of the breathing mixture due to a leak in a badly fitting mask).

6. During positive pressure breathing the chest and lungs tend to become distended and respiration becomes increasingly difficult as the pressures increase. Normal resting breathing, although involuntary, involves active inspiration and passive expiration. During pressure breathing the pattern is changed to a conscious but relatively passive inspiration and a very active expiration, during which the respiratory muscles have to work against the pressure of oxygen supplied.

7. Breathing against a high positive pressure is tiring and also creates abnormal pressure relationships between the lungs and the rest of the body so that man's tolerance to pressure breathing is limited. This tolerance can be improved by the use of efficient personal breathing assemblies, a good personal subjective response and pressure breathing training which includes progressive exposure to graduated levels of positive pressure breathing up to the maximum performance of the individual's pressure breathing assembly. In the untrained individual there is a tendency to overbreathe (see paragraph 15) and practice makes it easier to control the breathing pattern.



This graph shows the level of positive pressure breathing required to maintain a 'lung equivalent' of 12 000 m (40,000 ft).

Fig.9 Positive Pressure Breathing (shown in metres and feet)

8. The floor of the mouth and throat begin to distend when the breathing pressure exceeds 10-15mm Hg. This can lead to considerable discomfort at higher pressures and limits the use of an oxygen mask to about 75mm Hg pressure, even when it is used with garments which provide the appropriate counter-pressure on the chest. These garments are necessary at pressures greater than 30mm Hg (see paragraph 10).

9. Aircrew who are required to fly at particularly high altitudes might, in emergency, need to breathe oxygen at pressures greater than 75mm Hg, and in order to do so will need a pressurised helmet. This allows the breathing pressure to be applied also to the outside of the face and neck and prevents the discomfort which is associated with an oxygen mask at high breathing pressures. The neck support allows the wearer to speak quite clearly at pressures considerably in excess of 75mm Hg, whereas with a mask this would be virtually impossible.

10. Reference has already been made to the distension of the chest and lungs and reversal of the normal breathing pattern which is brought about by positive pressure breathing. These difficulties and potential hazards are reduced by applying counter-pressure to the outside of the chest wall so that as the pressure builds up inside the lungs, an equal pressure is applied to the outside of the chest. This is achieved by means of pressure garments; these are referred to in paragraph 13 and examples can be seen in Chapter 19, Plates 8 and 9. Even though the unsupported chest can stand pressures up to 55mm Hg before there is a risk of lung damage, counter-pressure is normally provided for breathing pressures exceeding 30mm Hg, since it prevents over inflation of the lungs and makes expiration easier.

11. One of the most important factors which limit positive pressure breathing is the effect which these abnormal pressure relationships have on the circulatory system. The rise in pressure is transmitted to the cardiovascular system and restricts the return of venous blood from the tissues to the heart; at the same time the normal arterial flow continues and the peripheral veins become distended with blood. As the pressure in the veins rises, the venous return to the heart

is ultimately restored and in effect the circulation in the limbs is maintained by displacement of blood from the trunk. This blood pooling effectively takes blood out of circulation and this is further aggravated by a temporary shift of some of the fluid from the blood into the tissue spaces. These factors cause a reduction in the output of the heart because of a lowering of pressure in the right atrium of the heart (see Fig.5). There is a limit to the reduction in circulation which the body can stand because the blood supply to the brain and other organs is reduced, thus this effect dictates the level and duration of pressure breathing which individuals can tolerate before feeling faint.

PRESSURE GARMENTS AND PARTIAL PRESSURE ASSEMBLIES

12. In order to aid respiration, counter pressure is supplied to the outside of the chest wall when the breathing pressure exceeds 30mm Hg (see paragraph 10). It is better to provide counter-pressure over the whole surface of the trunk, however, since this virtually eliminates the downward movement of the diaphragm which would otherwise occur. The counter-pressure over the trunk thus prevents overdistension of the lungs and it also reduces the degree of hyperventilation which would otherwise be caused. Counter-pressure over the abdomen and limbs also reduces the amount of blood which is displaced from the chest, thereby maintaining the circulation by increasing the output of the heart; the greater the area of counter-pressure the more effective it is.

13. Counter-pressure may be produced in a number of ways, but most usually this is done by means of gas-filled bladders in suitable articles of clothing (see Chapter 19). The bladders are inflated by a supply of oxygen from the pressure breathing oxygen regulator. The particular type of positive pressure breathing assembly depends upon the role of the aircraft, its operating altitude and the degree of protection required in the event of loss of cabin pressure. In effect, this depends upon whether or not an individual needs to remain at that height or whether he can descend immediately.

14. A partial pressure assembly is so called because only part of the body's surface is pressurised and it can provide adequate

protection for aircrew who, in the event of a loss of cabin pressure, are able to descend below the height which is critical for pressure breathing, namely 12 000 m (40,000 ft). The extent to which the surface area of the body is covered depends upon the degree of protection required (see Chapter 19, Plates 8 & 9). The assembly may consist simply of a pressure breathing mask and a pressure jerkin which covers the trunk alone or the garment may extend to cover the limbs and arms also. In certain cases, the conventional anti-G suit is inflated as part of the pressure breathing assembly, thereby supplying counterpressure to the lower limbs (see Chapter 19, Plates 8a & 14). In order to provide protection at very high altitude, the mask may be replaced by a pressure helmet (see Chapter 19, Plates 9, 10 & 13). If, on the other hand, the task requires that the aircraft remains at altitude after losing cabin pressure, each crew member must be provided with a pressure garment which will protect him for a longer time than is possible with a partial pressure assembly. This would necessitate wearing a full pressure suit which is, in effect, a tailored pressure cabin. It is more cumbersome than most partial pressure assemblies and less easy to put on (see Chapter 19, Plate 9b).

HYPERVENTILATION

15. Hyperventilation can be defined as lung ventilation in excess of the body's needs and denotes an overriding of the normal automatic control of breathing which is usually exerted by the respiratory centre in the brain (see Chapter 3, paragraph 8). It may be the result of emotional stress or because an individual has taken over conscious control of respiration, such as during positive pressure breathing.

16. During hyperventilation the lungs are flushed out more than is necessary to remove the quantity of carbon dioxide which the body is producing. This leads to a marked fall in the partial pressure of carbon dioxide in the blood passing through the lungs. Almost invariably the effects of this condition are first felt in the arms and hands, where the initial symptoms are numbness and tingling of the fingers. This 'pins and needles' sensation in the extremities is very typical and is usually associated with a vague feeling of unreality,

palpitations, faintness and dizziness. If excessive hyperventilation persists the muscles of the hands and fingers go into spasm; the feet may also be affected. The symptoms are due to the lowered PCO_2 causing increased excitability of the muscles which tend to go into a state of sustained contraction. If the hyperventilation continues, unconsciousness may supervene shortly afterwards.

17. The following points should help to prevent the onset of hyperventilation or remedy the condition should it begin:

(a) A high standard of training breeds confidence and this is, without doubt, the best means of preventing hyperventilation.

(b) Learn to breathe in a normal manner, particularly when carrying out such tasks as pressure breathing.

(c) Beware the tendency to over-breathe during periods of intense concentration or tension.

(d) Do not try to overcome suspected hypoxia by forceful over-breathing.

18. When flying at cabin altitudes at which hypoxia could occur and there is any doubt as to whether symptoms are due to hyperventilation or hypoxia, always assume that the problem is hypoxia and carry out the appropriate oxygen drill immediately.

CONCLUSION

19. In this chapter, the principles involved in preventing hypoxia at various altitudes have been considered. Aircrew should familiarise themselves thoroughly with the particular oxygen equipment in their aircraft and keep in practice in its use; by so doing this very serious hazard, hypoxia, will be minimised.

- **HYPOXIA IS A SERIOUS HAZARD.**
- **OXYGEN SYSTEMS MAINTAIN AN ADEQUATE PAO_2 AUTOMATICALLY.**
- **THE THRESHOLD OF PRESSURE BREATHING IS 12 000 M (40,000 FT).**
- **PRESSURE BREATHING REQUIRES TRAINING.**
- **KNOW YOUR OXYGEN ASSEMBLY THOROUGHLY.**
- **TAKE GREAT CARE OF OXYGEN EQUIPMENT.**

CHAPTER 6

EFFECT OF DECREASED BAROMETRIC PRESSURE

INTRODUCTION

1. The preceding chapter dealt with the effects caused by a reduction of the oxygen tension in the inspired air (PIO_2). Hypoxia is not, however, the only problem associated with a decrease in atmospheric pressure. This chapter deals with decompression sickness which is unassociated with a reduction in PIO_2 but caused nevertheless by exposure to lowered atmospheric pressure. The chapter which follows this will consider the effects of changing atmospheric pressure on gases trapped in the body.

2. In the case of hypoxia, the significance of the lowered atmospheric pressure was the effect that it had on the tension of one of the constituent gases in the inspired air, namely the oxygen. Decompression sickness, on the other hand, is caused by the mechanical effect of lowering the atmospheric pressure over the body surface and not by any action that it has on a particular constituent of the inspired gas mixture.

DECOMPRESSION SICKNESS

3. 'Decompression sickness' is the name given to a group of symptoms which may occur as a result of exposure to reduced atmospheric pressure, excluding those which are due to hypoxia or the expansion of pre-existing gas contained in the hollow cavities of the body. It is sometimes referred to as 'bends', a term which is used to describe the commonest symptom of decompression sickness, namely, pain in the muscles or joints. The term 'dysbarism' has also been used to describe the effects of changing the total pressure on the body; it therefore includes all those effects due to pre-existing gas pockets in the body as well as to the specific entity which has been described as decompression sickness. For this reason, 'dysbarism' will not be used to describe this particular condition alone. Other terms which are sometimes used are aeroembolism (gas bubbles in the blood vessels) and

aeroemphysema (gas bubbles in the tissues). These have been mentioned for the sake of completion lest readers may hear them, but it is strongly recommended that the term 'decompression sickness' be used to describe this particular condition.

BEHAVIOUR OF GASES IN SOLUTION

4. There have been many theories put forward to explain these effects of lowered atmospheric pressure on the body and the most likely cause is explained by the so-called 'bubble theory'. This is based on one of the gas laws already mentioned in Chapter 2, namely 'Henry's Law'. Henry's law states that: the amount of gas that will dissolve in a solution and remain in solution, is directly related to the pressure of the gas over the surface of the solution. The gas principally involved in the formation of bubbles in the human body is nitrogen and the likeliest cause of decompression sickness is the liberation of nitrogen bubbles in the body due to the lowered atmospheric pressure.

5. The body is saturated with nitrogen which is in equilibrium with the partial pressure of nitrogen in the lung alveoli. When the total atmospheric pressure is decreased, the nitrogen tension in the lungs falls and the partial pressure of the body nitrogen is greater than that of the nitrogen in the lungs. There will therefore be a tendency for nitrogen to diffuse out of the blood, across the alveolar membrane and be exhaled. This means that there is an imbalance between the tension of nitrogen in the blood and in the tissues, aggravated by the fact that all the tissues of the body do not release nitrogen at the same rate. For example, blood and muscle release nitrogen quickly, whereas fat releases it slowly. When the environmental atmospheric pressure is lowered, therefore, the nitrogen in solution in the tissues, saturated at sea level pressure, will be in a state of supersaturation and under certain conditions will come out of solution. This has been likened to the formation of bubbles in a bottle of soda water when the pressure is released by removing the stopper.

6. At reduced atmospheric pressure, bubble formation is influenced by factors such as: movement of the tissues (which explains the significance of exercise as a predisposing factor), alterations in the circulation of body fluids and rapid changes in gas pressure. Bubbles appear in those areas around joint capsules and the insertions of tendons and ligaments; tending to be released in fatty tissues where there is the least blood supply and the greatest amount of dissolved nitrogen.

SYMPTOMS OF DECOMPRESSION SICKNESS

7. Decompression sickness can occur in apparently normal individuals who have no predisposing disease and there is wide individual variation in susceptibility. The symptoms of decompression sickness are as follows:

(a) BENDS – This is the commonest symptom of decompression sickness and consists of pain in the muscles or joints which may be mild or severe. Mild pain very commonly becomes severe or agonising if altitude is not reduced and an individual may ultimately collapse, (see sub-paragraph (e)); rarely, 'bends' pain may disappear without becoming severe. The commonest sites for the pain are: the upper part of the arm (near the shoulder), the knee, wrist and ankle; and more than one of these areas may be affected at the same time. The pain usually starts as a mild ache, not unlike the after-effects of unaccustomed exercise, but if it is allowed to continue it may become a deep pain spreading along the limb causing clumsiness, weakness and eventually complete disablement of the limb. When the pain is mild, the sufferer is inclined to rub the affected part to gain some relief but this action only makes matters worse. The symptoms usually pass off during descent, probably somewhere between 8 000 m (26,000 ft) and 6 000 m (20,000 ft), on the way down. In cases where the condition has arisen below 8 000 m (26,000 ft), the symptoms may not disappear until a descent has been carried out to some height below 6 000 m (20,000 ft). Some residual stiffness and even a mild ache may persist for some time. Reascent causes immediate recurrence of the pain.

(b) SKIN EFFECTS – Prickling or tingling sensations in the skin frequently occur but they are usually transient and of little significance. Localised skin rashes are sometimes visible.

(c) 'CHOKES' – This is the name given to a respiratory disturbance which may occur as a symptom of decompression sickness. It is really a misnomer however, as the subject does not choke. This denotes a sore, burning feeling in the centre of the chest, associated with pain on inspiration; there are also repeated paroxysms of coughing. It is not a very common symptom of decompression sickness but it must be taken very seriously and descent should be initiated as soon as possible preferably to below a height of 5 000 m (16,000 ft) or collapse may follow. Although the condition is relieved by descent (recompression) a residual soreness may remain. The 'chokes' may be preceded by bends pain in some cases.

(d) NEUROLOGICAL SYMPTOMS – The effects on the central nervous system are very varied and usually short-lasting. A temporary defect in the field of vision is a fairly common symptom. Frequently there is also a feeling of uneasiness or inability to concentrate and following recompression a severe headache may develop. It is rare for numbness and paralysis to occur at altitude, but they may arise as a complication of secondary collapse. Neurological symptoms should be treated seriously.

(e) COLLAPSE – A person who is suffering from decompression sickness may collapse with or without any other symptoms being present. This collapse is a typical faint; characterised by pallor, sweating, nausea, giddiness and then unconsciousness. So called post-decompression collapse may occur after return to ground-level and in a few cases up to 6 hours or longer after landing. This type of collapse is almost always preceded by some form of decompression sickness at altitude. In view of this possibility, it is wise to ensure that individuals who have had symptoms of decompression sickness are placed under medical surveillance as soon as possible and for at least 12 to 24 hours.

FACTORS WHICH PREDISPOSE TO DECOMPRESSION SICKNESS

8. There are a number of factors which influence the incidence of decompression sickness and these can be classified under two main headings, namely, general and personal:

(a) GENERAL FACTORS:

(1) ALTITUDE – There is considerable evidence that the altitude threshold for decompression sickness is 5 500 m (18,000 ft) although in fact it occurs only rarely below 6 000 m (20,000 ft). The frequency increases with altitude, particularly above 8 000 m (26,000 ft).

(2) RATE OF ASCENT – The rates of ascent which occur in aviation seem to be of little significance.

(3) DURATION OF EXPOSURE – The longer the time of exposure to high altitude, the greater the likelihood of an individual being affected by decompression sickness.

(4) EXERCISE – Exercise, at altitude, is one of the most important factors influencing the susceptibility to this condition. It is for this reason that both rubbing and repeatedly flexing the affected part are manoeuvres which will aggravate, rather than alleviate, the condition.

(5) RE-EXPOSURE – Re-exposure to altitude within a period of 48 hours increases an individual's susceptibility.

(6) TEMPERATURE – There is some evidence to suggest that low temperature increases the incidence.

(7) TIME OF DAY – There is evidence which shows that the likelihood of decompression sickness is related to the time of day; the incidence being highest in the morning and lowest in the late evening.

(8) SKIN DIVING – Under-water swimming during the 24 hours before flight, may facilitate or worsen decompression sickness in the air.

(b) PERSONAL FACTORS:

(1) AGE – There is a highly significant increase in susceptibility with age. For example, there is evidence to suggest that individuals in their mid-thirties are about three times more susceptible than those in their early twenties.

(2) BODY WEIGHT – It has already been pointed out that fat has a higher nitrogen content than other body tissues, so that obesity predisposes an individual to decompression sickness.

(3) RECENT INJURY – There is some evidence to suggest that recent joint and limb injuries increase the local susceptibility to bends pain but this is not absolutely certain.

(4) STATE OF HEALTH – The after-effects of alcohol and current infection both increase susceptibility.

PREVENTION OF DECOMPRESSION SICKNESS

9. Attention to the various factors which predispose an individual to decompression sickness, in particular cabin altitude, can help to prevent the condition. Pre-oxygenation (denitrogenation) also protects against decompression sickness; the degree of protection being related to the degree of denitrogenation of the body. This technique consists of replacing the nitrogen in the inspired air by oxygen and entails breathing 100% oxygen at ground level for some time before take-off. This procedure is time-consuming since it has to be carried out for at least an hour, and in some cases several hours, depending upon the altitude and duration of the intended exposure to low atmospheric pressure. For example, breathing oxygen at ground level for three hours will protect a high percentage of people during exposure to a height of 12 000 m (40,000 ft), for a period of three hours. Aircrew who pre-oxygenate on the ground must proceed to their aircraft and transfer to 100% oxygen on the aircraft system without breathing atmospheric air.

TREATMENT OF DECOMPRESSION SICKNESS

10. The treatment of decompression sickness is immediate recompression, as fast as is tolerable, by descending to a height below 6 000 m (20,000 ft) compatible, of course, with other dictates of flight safety. In severe cases, or if the symptoms persist, a landing should be made as soon as possible so that medical attention may be secured. Even if this recompression alleviates an individual's symptoms of decompression sickness, the medical authorities at the point of landing should be advised of what has occurred in flight. The individual can then be kept under surveillance for an appropriate period of time (at least 12-24 hours) lest post-decompression collapse should occur. In severe cases, the treatment of choice consists of hyperbaric therapy, the patient being exposed to pressures greater than sea-level in a hyperbaric (recompression) chamber.

BOILING OF TISSUE FLUIDS

11. A further effect of exposure to reduced atmospheric pressure is termed 'EBULLISM', namely, the so-called 'boiling' of tissue fluids. Above 19 000 m (63,000 ft), the total atmospheric pressure is less than the vapour pressure of body fluids at deep body temperature and in regions of the body where the hydrostatic pressure of the body fluids is low, 'boiling' can occur. There is a rapid, painless swelling of the affected parts and this has occasionally been observed in the hands of aircrew wearing partial pressure suits at these altitudes; it disappears on descent to below this height. This condition is in no way associated with a rise in body temperature and there is no residual disturbance of function. It can be prevented by applying local pressure to the area concerned, for example by wearing close fitting gloves to protect unpressurised hands. Ebullism is also partly self-limiting because as the water vapour is produced in the tissue spaces so the local pressure rises and when the absolute pressure reaches 47mm Hg, the vaporisation ceases, (see Chapter 7, paragraph 3).

CONCLUSION

12. Decompression sickness is associated with sustained flight at high cabin altitudes. It is a potentially serious condition which is associated with flying at cabin altitudes above 7 500 m (25,000 ft), or lower in some cases. This condition must be kept in mind when replanning a flight profile after loss of cabin pressure. Cases of decompression sickness should be treated very seriously and placed under medical surveillance as soon as possible.

- **DECOMPRESSION SICKNESS IS CAUSED BY EXPOSURE TO LOW PRESSURE.**
- **BEWARE PROLONGED EXPOSURES AT CABIN ALTITUDES ABOVE 7 500 M (25,000 FT).**
- **AGE AND WEIGHT ARE SIGNIFICANT PERSONAL PREDISPOSING FACTORS.**
- **TREATMENT IS BY IMMEDIATE RECOMPRESSION TO LOW ALTITUDE.**
- **MEDICAL SURVEILLANCE FOR 12-24 HOURS IS ESSENTIAL AFTER SYMPTOMS.**
- **CHECK LOCAL REGULATIONS REGARDING SKIN DIVING AND FLYING.**

CHAPTER 7

EFFECTS OF CHANGING BAROMETRIC PRESSURE ON GAS CONTAINING CAVITIES

INTRODUCTION

1. The body contains a number of gas-filled cavities which communicate with the surrounding atmosphere with varying degrees of efficiency. When the atmospheric pressure changes, the gas pressure in these cavities must achieve an equilibrium with the new pressure level or adverse effects will occur. This chapter describes these gas-filled cavities, methods which are used to assist pressure equalisation where necessary and the problems which arise when equilibration fails.

2. There are several structures in the human body which normally contain a quantity of gas. This may be air, as in the case of the ears and sinuses, atmospheric air modified by the process of respiration, as in the lungs, or quite different gases, such as those generated within the alimentary tract. The stomach contains a mixture of both air and gas generated by the processes of digestion.

3. These gases are influenced by changes in the pressure occurring outside the body, so that as atmospheric pressure decreases with increasing altitude the gases tend to expand. During descent the process is reversed and the gases tend to contract. Apart from any consequence of physical restraint affecting the gases, the expansion and contraction which occur in closed cavities, due to outside pressure change, do not take place according to the strict dictates of Boyle-Marriotte's Law, since this relates to dry gas. Gas in body cavities is saturated with water vapour at body temperature (37°C) and the relationship (PV = constant) is therefore modified in these circumstances (see Chapter 2, paragraph 13a). Assuming that the water vapour pressure at deep body temperature exerts a constant pressure of 47mm Hg, (see Chapter 3, paragraph 10), the relative gas expansion will occur according to the formula:

$$RGE = \frac{P_i - 47}{P_f - 47}$$

where: RGE = relative gas expansion

P_i = initial pressure (in mm Hg)

P_f = final pressure (in mm Hg)

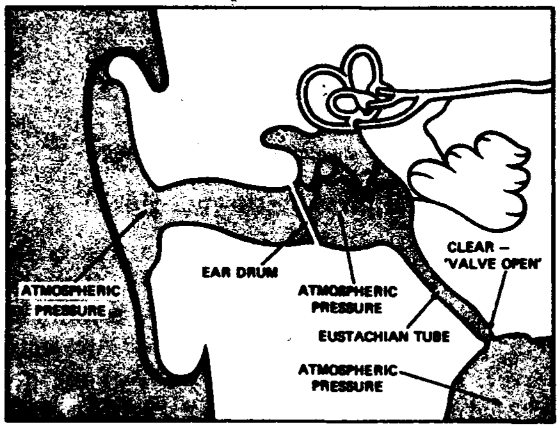
For a given pressure ratio, therefore, the greater the altitude the greater the gas expansion until at 19 000 m (63,000 ft) the relative gas expansion is theoretically infinite since the atmospheric pressure at that altitude is 47mm Hg. In practice, however, the stretching of the walls of the body cavities offer increased resistance to the gas expansion and cause a local rise in internal pressure (see Chapter 6, paragraph 11), so that the process tends to be self-limiting and infinite gas expansion cannot occur.

4. When there is free and unrestricted communication between these gas-filled cavities and the outside atmosphere, gaseous expansion causes no difficulty or discomfort. If, on the other hand, the pressure build-up cannot be relieved, it causes considerable pain and even incapacity; various sites where gases can be trapped and pressure fail to equalise, will be discussed individually.

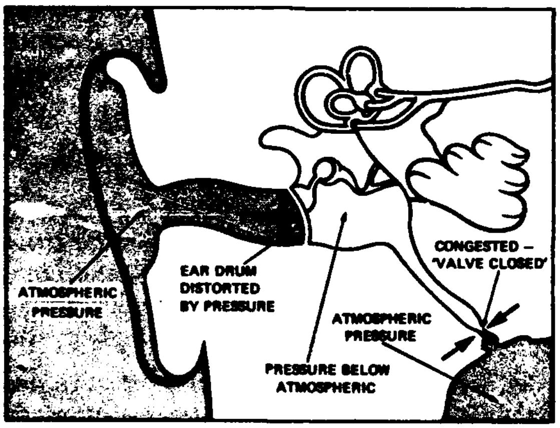
EFFECTS OF CHANGING PRESSURE ON THE MIDDLE EAR CAVITY

5. The cavity of the middle ear is separated from the exterior by a thin diaphragm, the ear drum, and communicates with the back of the throat through the Eustachian tube whose walls are soft and normally collapsed together.

6. During ascent, as the atmospheric pressure decreases, the expanding air in the middle ear cavity readily escapes along the Eustachian tube, so that the pressure remains equal on both sides of the ear drum (see Fig.10a). The anatomical structure of the middle ear is such that the air can escape easily, so that it is unusual for difficulties to occur during ascent. This intermittent passive ventilation of the middle ear is appreciated as a popping sensation as air escapes down the Eustachian tube.



(a) Diagram of the ear showing the pressure in the middle ear cavity equal to atmospheric.



(b) This shows the effect of increasing barometric pressure during descent causing an inward distortion of the ear drum due to failure to ventilate the middle ear cavity, (Eustachian 'valve' closed – otitic barotrauma).

Fig.10 Pressure Effect on the Ear

7. During descent on the other hand, the collapsed walls of the Eustachian tube tend to act as a valve preventing air from flowing back into the middle ear cavity; the resultant pressure build up on the outside of the ear drum distorts the drum inwards (see Fig.10b). The degree of distortion increases as the descent continues, unless atmospheric air can enter the middle ear cavity through the Eustachian tube to counteract it. This pressure differential across the drum causes a sensation of fullness in the ear, a decrease in hearing and local pain, in that order. If the descent continues still further, without equilisation of pressure across the ear drum, the pain becomes intense and the ear drum might perforate. This condition is known as 'otitic barotrauma', namely, damage to the ear by pressure. In certain susceptible people a rapid build up of pressure in the middle ear cavity can affect the organs of balance in the inner ear and cause vertigo (see Chapter 11, paragraph 10g).

8. Unlike the passive ventilation of the middle ear cavity which takes place during ascent, it is usually necessary to perform some active maneouvre to clear the ears during descent. Several maneouvres can be used to open the Eustachian tubes, such as yawning, swallowing, or pushing the jaw forward and these should be carried out at regular intervals during the descent. If these actions fail, trying to 'blow the nose', whilst keeping the nose and mouth tightly closed, is very effective; this is known as the Valsalva maneouvre. Each person soon finds the method of ventilating the middle ear cavity which suits him best.

9. During descent, the ears should be cleared regularly since difficulties are likely to occur if the pressure build up across the drum is allowed to become excessive. For example, if the pressure differential reached 50mm Hg, pain would be very severe and at 90mm Hg it would not be possible to equalise the pressure by any voluntary effort; continued descent at this stage would certainly cause the ear drum to burst.

10. If voluntary maneouvres fail to relieve the discomfort in the middle ear, it is best to climb again (fuel supply permitting) to the altitude at which the pressure on the two

sides of the drum is equal, or nearly so. The subsequent descent should be carried out at a reduced rate, clearing the ears regularly this time. The logarithmic relationship between pressure and altitude means that the ears have to be cleared more often at lower levels, (see Chapter 2, paragraph 9).

11. A head cold is likely to cause congestion and swelling of the lining of the Eustachian tubes, in the same way that it causes nasal congestion. This makes it difficult or impossible to clear the ears because of the resultant narrowing of the Eustachian tubes. For this reason, flying should be avoided when suffering from a head cold or any other condition which causes inflammation in that area of the body, for example, a sore throat or sinusitis (see paragraph 12). When in doubt, check with your Medical Officer; a short period of preventive grounding is quicker and safer in the long run.

THE NASAL SINUSES

12. The nasal sinuses are cavities located within the bones of the face and skull. They communicate with the nose along narrow bony tunnels and have a lining similar to that of the nose. During ascent and descent, the expanding and contracting air within the sinuses is normally free to communicate with the nose so that there is no more than a slight tickling sensation as the pressure within the sinuses equilibrates with atmospheric pressure. When the lining of the sinuses is inflamed, which occurs with a severe head cold or sinusitis, swelling of the lining may obstruct the outlets. This causes pain during descent; a condition known as 'sinus barotrauma'. The pain may be felt in the cheek, forehead or deep in the head and in severe cases it may be accompanied by watering of the eyes, making it difficult to see. Symptoms as severe as this could jeopardize a pilot's ability to control his aircraft, so that infection or inflammation of the sinuses is a further reason for temporary grounding.

13. To prevent excessive pain in the sinuses the pressure must be equalized as rapidly as possible. Unfortunately the Valsalva maneouvre is not so effective in clearing blocked

sinuses as it is in clearing ears, because auto-inflation of the sinuses is difficult to achieve. If not successful, the pressure change must be reversed as rapidly as possible by climbing to a higher altitude, then descending again more slowly. In a decompression chamber, where a decongestant nose spray is available, this can be used to great effect since it will help to shrink the lining of the communicating passages and create a clearer airway. The subsequent descent should then be carried out at a slower rate to aid equalization of the pressure.

ABDOMINAL DISTENSION

14. Even in healthy individuals, the stomach and intestines contain a certain amount of gas which, at ground level, amounts to about one litre. On ascent, this gas expands and depending upon its location, escapes from the mouth or anus. Certain individuals have difficulty in venting this gas even at modest rates of ascent. This is most common amongst inexperienced aviators; the incidence of discomfort due to the expansion of abdominal gas being insignificant amongst experienced aircrew. The greater the rate of ascent, the greater is the problem of expelling the gas as quickly as it expands. This causes symptoms which vary from mild abdominal discomfort to severe pain in exceptional cases. The problem may be aggravated if an individual is suffering from an intestinal infection or has eaten too many gas-forming foods. Typical examples of such foods are: raw apples, dried beans and peas, cabbage, cauliflower, cucumber, turnip, brussel sprouts, high roughage foods such as celery and bran and carbonated drinks. With experience, aircrew soon learn whether or not they have difficulty in venting abdominal gas and can adjust their diet to reduce the amount of gas in the bowel. Those who regularly fly at very high altitude learn to avoid foods which they know "disagree" with them. It is also important to remember that chewing food well before swallowing lessens the susceptibility to gaseous discomfort at altitude.

15. Before carrying out a practice decompression in a chamber, care should be taken to ensure freedom from

abdominal discomfort due to trapped gas, otherwise the sudden expansion of gas during the decompression could cause a faint. This entails no more than a sensible diet before the chamber run and venting the gas as it expands during the climb – as in flying.

EFFECTS OF CHANGES OF PRESSURE ON THE LUNGS

16. The lungs can also be affected by rapid changes of environmental pressure. Only extremely rapid rates of decrease in environmental pressure could cause damage to the lungs by over-expanding them to the point of rupture because of the relatively wide bore air passages along which the lung air can escape; greater restriction is caused by the oxygen equipment. Lung damage due to rapid or explosive decompression has never occurred in the air, even in an aircraft with a high differential cabin, so that this is not a real hazard. It would be dangerous, of course, if an individual were foolish enough to hold his breath during a practice decompression since such a maneouvre, particularly with inflated lungs, would carry a risk of lung rupture, because the expanding lung gas would be sealed off. During practice decompressions, subjects who are breathing normally need not worry since the expanding gas will certainly find its way out.

THE TEETH AND GUMS

17. Toothache may be caused by marked changes in atmospheric pressure, a condition known as 'barodontalgia'. Typical causative factors are large deep-seated fillings which are unlined and various degrees of inflammation or degeneration of the tooth pulp. The latter is probably the more common and represents an early stage in a condition which would ultimately cause toothache at ground level. This is another reason why aircrew should take great care of their teeth and attend dental clinics regularly, quite apart from the general beneficial effect which healthy teeth and gums have on their health in general.

CONCLUSION

18. Changing barometric pressure, particularly if it is rapid, will cause discomfort unless the pressure in gas containing cavities equilibrates with the new pressure level. Aircrew can soon learn to cope with these changing pressures, but should remember the hazards associated with throat infections and seek treatment. Finally, attention is drawn once more to the logarithmic relationship between atmospheric pressure and altitude. The greatest pressure change, for a given difference in height, occurs at the lower levels and it is during descents at these levels that the greatest difficulty will be experienced in clearing the ears.

- **DIMINISHING ATMOSPHERIC PRESSURE CAUSES GAS EXPANSION IN THE BODY.**
- **EUSTACHIAN TUBES ACT LIKE VALVES AND MUST BE OPENED DURING DESCENT.**
- **BEWARE THE DANGER OF FLYING WITH UPPER RESPIRATORY INFECTION.**
- **AIRCREW EXPOSED TO LOW ATMOSPHERIC PRESSURE SHOULD WATCH DIET.**
- **REGULAR DENTAL CARE CAN PREVENT PAINFUL BARODONTALGIA.**

CHAPTER 8

CABIN PRESSURISATION AND RAPID DECOMPRESSION

INTRODUCTION

1. The chapters dealing with the effects of altitude showed the need for protection against hypoxia and decompression sickness. In most modern aircraft these problems are overcome by pressurising the aircraft cabin, thereby providing a degree of protection which is dependent upon the pressure difference. This lowers the cabin altitude to a level which is equivalent to the ambient atmospheric pressure plus the cabin pressure differential. For example, an aircraft with a cabin differential of 600 gm/cm^2 (8.5 psi) which is flying at an actual altitude of 10 000 m (33,000 ft), where the atmospheric pressure is 270 gm/cm^2 (3.8 psi), would have a cabin altitude of 1 500 m (5,000 ft) since that is equivalent to an atmospheric pressure of 870 gm/cm^2 (600 + 270) or 12.3 psi (8.5 + 3.8). In that situation the occupants of the pressure cabin, being at 1 500 m (5,000 ft), would have no need to breathe additional oxygen to avoid manifest hypoxia and they would also be protected completely from decompression sickness.

ENVIRONMENTAL REQUIREMENTS OF PRESSURE CABINS

2. Since the majority of aircrew are accustomed to living at pressures approximating to the sea level value, it would seem to be ideal to maintain sea level pressure in an aircraft cabin at all times. This solution is usually impractical however, due to the weight and complexity of aircraft equipment which would be necessary. For example, a differential pressure of 1 atmosphere represents more than 1,000 gm pressure for each square centimetre of cabin wall and transparency (> 2,000 lb/ft^2). By accepting a cabin altitude of 2 500 m (8,000 ft) instead of pressurising down to sea level, this pressure would be reduced by as much as a quarter to 750 gm/cm^2 (1,500 lb/ft^2). In military aircraft

the added risk of loss of cabin pressure due to enemy action must also be considered, since the greater the cabin differential the greater is the hazard from sudden pressure loss. For these reasons aircraft are designed with cabin differentials which represent a compromise between the physiological ideal and the aircraft role and performance.

3. Different aircraft types have their own pressurisation characteristics and it is impractical to discuss these specifically in this book. In general, however, pressure cabins fall into two broad categories namely low and high differential cabins and in any case this subdivision is quite sufficient to explain the characteristics of pressure cabins and the effects of pressure loss. High differential cabins usually maintain a cabin altitude of the order of 2 500 m (8,000 ft) or below throughout the greater part of the operating altitude of the aircraft. Low differential cabins, on the other hand, maintain a cabin altitude of approximately 7 500 m (25,000 ft) at high aircraft altitudes. This is discussed in greater detail in paragraph 7.

4. The advantage of a high cabin differential is that it protects the occupants of the cabin from any serious effects due to hypoxia without having to use personal breathing equipment. Nevertheless, even at a cabin altitude of 2 500 m (8,000 ft) there is a small decrement in crew performance due to hypoxia (see Chapter 4), including some loss of night visual acuity. There is no risk of decompression sickness at this altitude.

5. Large bomber-type aircraft normally have high differential cabins. These aircraft must be able to operate at high altitude for long periods and also they are able to carry the weight of pressurisation equipment which is necessary. These aircraft are usually fitted with a facility which allows the crew to select a low (combat) differential when they consider it necessary, (e.g. during enemy action). A low differential cabin is usually found in small short duration fighter or trainer type aircraft in which the crew use personal oxygen equipment routinely. These aircraft usually have a very small pressure cabin and this is one of the factors which contributes to a very rapid loss of cabin pressure if the cabin

is damaged. The question of loss of cabin pressure is discussed later in this chapter, (see paragraph 9).

6. Passenger carrying aircraft require high differential cabins otherwise passengers would require personal oxygen equipment to prevent hypoxia. Clearly such a situation would be unacceptable to passengers and as the operating heights of passenger-carrying aircraft increase, so the pressure differential must be made greater.

METHODS OF PRESSURISATION

7. A pressure cabin is built strong enough to withstand its maximum intended pressure differential plus an element for safety and is sealed to meet certain laid down standards for leak rates. Pressurisation is then achieved by tapping air from a suitable stage of the engine compressor, cooling it and leading it into the cabin. In some aircraft, a separate engine-driven compressor is used. The differential pressure level is then set by controlling the inflow of compressor air together with a fine control for regulating the rate of escape of air from the cabin by means of a barometrically operated relief valve. The cabin altitude is usually allowed to increase with aircraft altitude until a height of between 1 500 to 2 000 m (5,000 to 8,000 ft) is reached when barometric control then maintains the cabin at that altitude until the maximum differential pressure for that aircraft cabin is reached. If the aircraft continues to climb, the maximum differential control takes over: the maximum differential pressure is maintained and the cabin altitude increases, maintaining that differential over ambient atmospheric pressure.

8. There are other methods of pressurising cabins. For example, space vehicles carry their own source of pressurisation which may be 100% oxygen (stored in liquid form) or a mixture of oxygen and an inert gas. It is advantageous to use an oxygen/inert gas mixture for reasons of safety.

LOSS OF CABIN PRESSURE

9. Loss of cabin pressure can vary from a slow leak, due to some minor mechanical fault such as a failure of the canopy

seal, to a rapid or even explosive decompression due to rupture of the cabin wall or loss of the canopy or a window. The occurrence of a rapid decompression is readily indicated by a loud noise due to the sudden release of pressure. The compressed air within the cabin 'roars' out of the defect at a velocity near the speed of sound until the cabin pressure reaches that of the surrounding air. As this air leaves the cabin, so the remaining gas expands, causing the temperature of the air within the cabin to drop to its dewpoint and water condenses out as a mist which can be so dense that it interferes with the occupant's vision. The loud noise plus misting has led crews to believe that their aircraft is severely damaged and on fire. In the case of a slow leak, there is no such dramatic indication. The first sign is likely to be the sound of a cabin pressurisation failure warning device; the illumination of the appropriate warning light or a cabin altimeter indication, depending upon the aircraft instrumentation.

AERODYNAMIC SUCTION EFFECT

10. In the case of a rapid decompression resulting from a defect in the cabin wall rather than a failure of the pressurisation system, the final cabin altitude may exceed the actual pressure altitude of the aircraft. This is due to the flow of air over the defect which tends to suck the residual air out of the cabin (aerodynamic suction effect), except in cases where the defect faces directly into the air stream. The magnitude of this effect varies with the aircraft type, the position of the defect in relation to the atmospheric air-stream and the aircraft's attitude and speed. In the worst case the height discrepancy could be such that the cabin altitude is many thousands of feet above the aircraft pressure altitude. This can, therefore, be a very important phenomenon because of the effect it can have on the crew and whether or not their personal oxygen equipment has the performance necessary to prevent hypoxia at that residual cabin altitude.

FACTORS GOVERNING RATE OF DECOMPRESSION

11. There are three main factors which govern the rate of decompression, namely, the volume of the pressure cabin, the

size of the cabin defect and the pressure ratio between the cabin and the outside atmosphere. Firstly, the larger the pressure cabin, the longer it will take for the air to escape during the decompression and conversely, small cabins will experience much more rapid decompressions for a given size of defect. It is for this reason that small fighter type cockpits have been designed with low differential cabins. Secondly, the larger the cabin defect the more rapidly will a decompression occur since a greater volume of air can escape in a given time. Finally, the higher the pressure ratio the longer it will take for the air to escape, due to its greater density within the cabin and thus the time of decompression will be prolonged.

HAZARDS OF RAPID DECOMPRESSION

12. The physiological significance of a particular decompression depends upon the pressure differential, the duration of decompression and the final cabin altitude. During the time of the decompression, the hazard potential is associated with the rapid expansion of gas within the body according to the pressure differential, duration of the decompression and aircraft altitude. The possible effects of rapidly changing pressures on the ears, sinuses, lungs and abdomen have already been discussed in Chapter 7. The hazards are in fact remarkably small under normal conditions of flight and pressurisation. Tests have shown that, with the pressure differential chosen for various types of aircraft, (in relation to their cabin volume and potential leakage, based on canopy and window size), the rate of expansion of gas and associated increase in pressure within the body cavities, are counterbalanced by the rate of leakage from the body, which prevents excessive over-pressures.

13. The most severe hazards associated with a rapid decompression are therefore likely to be those which follow the event, if the final cabin altitude is high. The first to be considered is hypoxia, which is particularly significant for three reasons. Firstly, in the case of high differential cabins with a "cruising" cabin altitude of 2 500 m (8,000 ft) or lower, the crew is most unlikely to be using oxygen equipment at

the time of the decompression. Secondly, if the final cabin altitude is very high (i.e. above 10 000 m : 33,000 ft) the times of useful consciousness for the various crew members breathing air may be reduced by as much as one third from the figures which would normally be expected for that ambient altitude. This is due to the fact that, during the escape of gas from the lungs, the partial pressure of oxygen in the alveoli is reduced to below 40mm Hg which is the approximate value for the oxygen tension in the venous blood so that there is an actual reversal of the oxygen diffusion gradient across the alveolar membrane and oxygen passes back into the lungs from the venous blood. Immediately following a rapid decompression to these very high altitudes, therefore, the arterial blood leaving the heart would be carrying little or no oxygen and the onset of hypoxia would be very rapid – if the person were breathing air at that time. This shows the need for having a personal oxygen supply readily available, preferably with the oxygen mask already fixed on the helmet. It also shows the advantage of having the pilot or one of the pilots on oxygen the whole time. Thirdly, the final altitude after decompression may be above 12 000 m (40,000 ft) and positive pressure breathing would be required to prevent hypoxia.

14. When the immediate problem of hypoxia has been overcome, the crew may still be faced with the possibility of developing symptoms of decompression sickness if for any reason there is need to continue the flight at a cabin altitude greater than 7 500 m (25,000 ft). Certain particularly susceptible individuals might even develop decompression sickness at an altitude as low as 5 500 m (18,000 ft). The likelihood of this occurring will also depend upon the duration of flight at these altitudes and this has been discussed in Chapter 6.

15. Depending upon the size and position of the defect in the cabin structure, cold may also limit sustained flight at altitude after a rapid decompression. If, for example, the canopy has been lost or the windscreen shattered, the wind chill effect could be very large and force the crew to descend, (see Chapter 9).

16. Finally there is another aspect of severe or 'explosive' decompression which should be mentioned, namely, the possible danger to the passengers or crew, in transport or bomber aircraft, of being displaced from their seats if they are not restrained by a harness at the time of decompression. The violent outrush of air, through a hatch or window opening, could endanger aircraft occupants who are not strapped in. They can be pulled out of their seats and even out of the aircraft, in extreme cases, depending upon the severity of the decompression and their position in relation to the defect in the aircraft structure.

PROCEDURES AFTER LOSS OF CABIN PRESSURE

17. Immediate steps must be taken to prevent hypoxia, (see Chapter 4, Table 2). The action necessary will depend upon the residual cabin altitude, the type and performance of the personal oxygen equipment and whether or not it is being worn and functioning at the time of the decompression. If the resultant cabin altitude is greater than 12 000 m (40,000 ft) the subsequent action will depend upon the type of positive pressure breathing assembly being used. A full pressure suit, which provides the wearer with the capability of staying at altitude and which is functioning correctly, will remove the danger of hypoxia. If, on the other hand, a partial pressure assembly with only a 'get-you-down' capability is being worn, an immediate descent at maximum rate will be necessary, through 12 000 m (40,000 ft). This is due to the time limit associated with this type of assembly before the wearer feels faint due to circulatory disturbances (see Chapter 5, paragraph 11). In either case, the remainder of the sortie should be planned according to the circumstances, bearing in mind operational necessities, fuel state of the aircraft, the effects of low cabin temperatures on both the occupants and their equipment and the possibility of the onset of decompression sickness.

CONCLUSION

18. The pressure cabin is an essential part of the modern high performance aircraft, without which it would not have

any useful high altitude capability. Without pressurisation, aircrews would only be able to carry out high altitude flying by the continuous use of personal oxygen equipment. At very high altitude, this would be cumbersome and have an adverse effect on their efficiency and performance during the flight. On the other hand, however attractive the concept of a so-called 'shirt-sleeve' environment might be, it can never be achieved fully in a military aircraft even with a pressure cabin. The very purpose of the aircraft exposes it to the risk of cabin damage resulting in an immediate need for a suitable personal oxygen assembly to prevent hypoxia.

- **THE PRESSURE CABIN IS ESSENTIAL TO A HIGH PERFORMANCE AIRCRAFT.**
- **IMMEDIATE EFFECTS OF DECOMPRESSION ARE UNLIKELY TO BE HAZARDOUS.**
- **AERODYNAMIC SUCK CAN RAISE FINAL CABIN ALTITUDE CONSIDERABLY.**
- **HIGH ALTITUDE DECOMPRESSION EXPOSES CREW TO HYPOXIA, COLD, DECOMPRESSION SICKNESS.**

CHAPTER 9

EFFECTS OF EXTREMES OF TEMPERATURE ON THE BODY

INTRODUCTION

1. Aircraft are required to operate over a wide range of speed and altitude which means that they are also exposed to wide ranges of temperature. It is no longer realistic, therefore, to consider ground climatic conditions alone when examining the effects of temperature on the body. The performance characteristics of modern aircraft can introduce gross temperature changes during a single sortie, even if the point of departure is located in a temperate climate. The flexibility of modern air power also means that it is more common for aircrews to operate at short notice from bases with climatic conditions vastly different from their own. Within minutes of taking off from an airfield whose ground temperature may be more than 45°C (113°F), an aircraft can be flying at an altitude at which the outside air temperature is of the order of −56°C (−70°F). If the mission calls for a low-level phase, the temperature of the aircraft will be increased above the level of the outside air temperature, because of the kinetic heat generated by the air friction over the aircraft surface.

2. The aircraft cabin conditioning system is designed to control cabin temperature over a fairly wide range of temperatures. There are occasions however, when the cockpit temperatures cannot be controlled adequately: these arise particularly at very high speed near the ground, or at very high altitude. Thus the temperatures become excessive to the point of discomfort and can interfere with efficient crew performance. Aircrew will also be exposed to extremes of temperature during high altitude bale-out or survival situations on land or sea (see Chapter 17).

3. The effects of exposure to extreme temperatures are not restricted to the more dramatic conditions such as heat-stroke or frostbite. Temperature variations within these extreme

limits can have a detrimental effect on a person's ability to perform a skilled task. It can be difficult to relate this performance loss to the particular temperature level, but if the temperature is allowed to deviate markedly from the normal comfort zone, a decrement in skilled performance will eventually ensue.

SOURCES OF COLD

4. The ambient air temperatures at various altitudes are listed in Chapter 2, Table 1. These data show that the air temperature falls progressively throughout the troposphere to about −56°C (−70°F) at about 11 000 m (36,000 ft). In the stratosphere the temperature is fairly constant at that figure, (see Chapter 2, paragraph 3). During high altitude bale-out, therefore, an individual is exposed to very low ambient temperatures, which is one of the reasons for delaying parachute opening until lower altitudes are reached, (see Chapter 16, paragraph 4). The low temperature problems associated with cold weather survival are dealt with in Chapter 17.

SOURCES OF HEAT

5. Apart from the heat produced in the body by the metabolic processes, there are four main sources of heat which are significant to aircrew. Firstly, the climatic effects associated with aircraft operations in the tropics or subtropics; secondly, heat sources in the cockpit area due to avionic components; thirdly, the added heat load induced by wearing thick or rubberised protective flying clothing (see Chapter 19) and fourthly, the effect of climatic kinetic heating. The temperature rise due to kinetic heating is given by the formula:—

$$T°C = 0.85 \left(\frac{V}{100}\right)^2,$$

where, T°C = temperature rise in °C

V = indicated airspeed in knots

For example, at an airspeed of 600 knots; the increase in temperature due to kinetic heating would be just over 30°C.

BASIC PRINCIPLES OF HEAT TRANSFER

6. It is useful to examine various physical processes of heat transfer, since these indicate the areas of greatest significance when considering the problems of normal heat exchanges with the environment and thermal stress:—

(a) CONDUCTION describes heat transfer from one part of an object to another part or from one object to another in physical contact. The amount of heat which is transferred between man and his surroundings by this process is small since conduction involves contact and large quantities of heat cannot be exchanged without risk of skin burns.

(b) CONVECTION denotes heat exchange between an object and the currents of gas or liquid which flow past it, causing it to gain or lose heat, according to whether it is colder or hotter than its immediate surroundings. Relative movement of air over the body, either because of an increased windspeed or movement of the body through the air, is therefore very significant. The so-called 'wind-chill effect' is very important in the low temperature situation, since it aggravates heat loss from the body (see paragraph 17 and Table 3).

(c) RADIATION refers to the transfer of heat or energy between two bodies of different temperatures, in the form of electro-magnetic waves. Heat radiates from the relatively hotter to the cooler body. The magnitude of heat loss or gain by radiation depends upon the size, shape and emissivity of the body surface and on the difference between the fourth powers of the absolute temperatures of the skin and the surrounding objects.

(d) EVAPORATION occurs when water passes from a liquid to a gaseous state and energy must be supplied. The evaporation of water from the body's surface therefore provides a large potential heat loss and this mechanism has a significant influence on thermal balance. It requires 580 calories of heat to change one gm of water into vapour at body temperature.

BODY HEAT PRODUCTION AND TEMPERATURE REGULATION

7. Man is homeothermal, that is, he maintains his body temperature constant in spite of wide variations in environmental temperatures. This term 'body temperature' refers to the temperature of the deep structures in the body and under normal conditions, at rest, it is maintained between 36° to 37.5°C (97° to 99.5°F). The skin, on the other hand, is usually at a lower temperature than the deeper structures. The body produces its own heat internally by the continuous metabolism of food-stuffs and because of its large physical bulk, is able to withstand minor environmental changes for several hours with a minimum change in body temperature. As the degree of temperature stress increases, however, various physiological processes within the body are called upon to maintain a constant body temperature.

8. If the deep body temperature is to remain constant the amount of heat gained from the body's various metabolic activities and from any environmental sources, by convection and radiation, would need to be balanced exactly by the amount of heat lost to the surroundings. According to environmental conditions, these heat exchanges can be represented as follows:–

$$Mcfp \pm C \pm R - E = \pm S,$$

where, Mcfp is the amount of heat which the body derives from the metabolism of carbohydrate, fat and protein,

C and R represent the amount of heat which the body gains or loses through convection and radiation, (plus a little by conduction),

E is the amount of heat which the body loses through the evaporation of sweat,

S represents the total heat lost or gained by the body tissues.

9. In man, the heat and water loss from the lungs compared with the skin is small, except at heavy work loads and

in conditions of extremes of temperature. In these circumstances, the exchange of heat across the lungs by convection and evaporation may become significant.

10. The regulation of body temperature is ultimately controlled by the thermo-regulatory centre in the brain which co-ordinates the activities producing either heat conservation or heat dissipation. Temperature regulation acts reflexly in that stimulation of special receptors in the skin set up appropriate responses, such as sweating and the alteration of blood flow through the vessels in the skin. These receptors cannot by themselves ensure temperature regulation. The thermo-regulatory centre reacts directly to local temperature changes in the blood supplying that part of the brain, as well as to these surface differential temperatures receptors and is responsible for the overall co-ordination of temperature regulation.

11. The normal mechanism of temperature control, which is triggered off by the responses from the brain, consists of adjusting the blood flow to the skin and tissues just beneath its surface. There are four main responses to exposure to heat and cold, as follows:–

(a) In cold conditions the blood vessels on the surface of the skin constrict, thereby reducing the amount of heat which is lost from the body surface.

(b) In extremely cold conditions a further response is necessary. Progressive muscular activity takes place, starting as an increase in muscle tension leading to involuntary shivering and voluntary limb movements, such as foot stamping and arm swinging: this increases heat production by the body.

(c) In warm conditions, the surface blood vessels open up to increase the heat loss from the skin.

(d) Sweating is a major response to an increase in environmental temperature. A certain amount of water loss takes place from the body surface the whole time, (insensible perspiration) but as the temperature rises, sweating occurs, causing body cooling by evaporation. This is a very important temperature regulating mechanism.

12. The evaporation of sweat is the body's main defence against heat stress. There are two types of sweat glands found in the skin; one type is to be found in the hair follicles of the axilla and groin, but their function is not thermoregulatory so they can be ignored in this context. The other type (eccrine), whose function is thermo-regulatory, is found all over the body surface. Those found on the soles of the feet and palms of the hand, however, respond to psychological stimuli as well as heat load. The eccrine sweat glands secrete a watery solution containing sodium chloride. Large quantities of water can be lost from the body through sweating and by varying the amount of sweat secreted, the amount of heat which the body can lose by evaporation can extend over a wide range.

EFFECTS OF HEAT

13. The disorders brought about by heat effects on the body, result from both the function and failure of the thermo-regulatory system. It is convenient, therefore, to examine the effects of heat stress under these two main headings:

(a) DISORDERS RESULTING FROM THE PROCESS OF THERMOREGULATION can be further subdivided into three types:

(1) Heat syncope is a sensation of giddiness or fatigue, resulting from loss of tone in the surface blood vessels, without any obvious diminution in water or salt. The patient recovers quickly when he lies flat and is reassured. It can best be prevented by limiting the work load on first entering a hot climate.

(2) Heat exhaustion due to water depletion is due to a failure to replace the amount of water which has been lost through prolonged sweating. It causes thirst, fatigue, dizziness and scanty urine output and is usually associated witn a shortage of drinking water, as in sea or desert survival situations. Prevention, therefore, depends upon a sufficiency of water supply and in desert conditions may amount to some 7 litres (12 pints) per day.

(3) HEAT EXHAUSTION DUE TO SALT DEPLETION is due to an inadequate replacement of the salt lost through sweating and causes fatigue, nausea, dizziness and cramp. It is usually the result of hard work in high environmental temperatures, during which the individual drinks plenty but fails to replace his salt loss. General weakness, giddiness and muscle cramps are particularly common in this condition and represent the differences between this type of heat exhaustion and that due to water depletion. Prevention is by ensuring an adequate intake of salt as well as fluid. Unacclimatised men may require as much as 15 to 25g of salt per day (according to the climatic conditions and work load), for the first 10 days, when the intake can then be reduced. This extra salt may only be taken if there is an adequate supply of water. The use of salt in tablet form should be treated with care because the tablets tend to remain undissolved in the stomach and pass through the intestines without being fully absorbed. If the food is normally salty (say 20 g/day), 1 g of salt should be added to each litre of drinking water; this can be increased up to 3 g per litre of drinking water if the conditions are severe.

(b) FAILURE OF THERMOREGULATION

Heatstroke is a very serious condition, which is due to a failure of the thermo-regulatory mechanism and in most cases is characterised by the sudden onset of delirium and coma. It is associated with a very high body temperature, above 40.6°C (105°F) and an absence of sweating. This condition is often fatal and so some means of effectively cooling the body must be instituted as soon as possible. The patient should be seen by a physician immediately, but if there is any delay, the unconscious person should be placed in a well-ventilated area and sprayed with cold water, to promote cooling by evaporation and convection in order to lower the body core temperature below 39°C (102°F)

quickly; cooling below that figure should be slower to avoid shock. This condition should be prevented, by ensuring that unacclimatised subjects are not exposed to large work loads in high environmental temperatures. Strict limits are usually laid down for operations in such tropical environments.

ACCLIMATISATION TO HEAT

14. Acclimatisation to heat is a process of adaptation, whereby the physiological strain produced by a given heat stress is progressively reduced. After some three weeks in a new hot environment, the body becomes acclimatised by means of changes which take place in the temperature regulating mechanism. The rate and degree of acclimatisation depend upon the severity of the environmental conditions and work load. In the first place, the normal sweat response becomes more efficient, which allows better evaporative cooling of the body. Secondly, there are changes in the blood circulation, whereby the total amount of circulating blood is increased. This means that the greater amount of blood in the skin which is required to increase heat loss does not interfere with the blood supply necessary for normal bodily functions.

EFFECTS OF COLD

15. When the environmental temperature falls below the level at which the maximum possible closing down of surface blood vessels has taken place, the temperature of the body begins to fall. A further lowering of temperature, or increase in time of exposure at that temperature, will both lead to an increase in the severity of the effect of cold. The body's protective mechanism of shivering will cease to be effective and give way to muscular rigidity and finally, as the body temperature continues to fall, unconsciousness will supervene.

16. Paradoxically, severe cooling of the hands and feet usually produces vasodilation or alternating vasodilation/vasoconstriction, thus aggravating the loss of heat from the body in cold conditions. This mechanism is not fully understood but may be due to paralysis of the constrictor muscles of the small blood vessels.

17. In low temperatures, the added effect of wind-chill can create a serious additional hazard, by lowering the effective temperature and increasing the possibility of frostbite (see Table 3).

FROSTBITE

18. Frostbite may occur if a part of the body is exposed to very low temperatures. In such a situation, the natural closing down of the surface blood vessels is so complete, that the circulation stops altogether. The onset of frostbite may be gradual and painless, but in some cases a feeling of numbness, or tingling, may provide useful warning signs. In the early stages, the affected part is white and waxy and surrounded by a red zone; later it goes purple or bluish and eventually the area becomes gangrenous.

19. The most commonly affected areas are the extremities, such as the fingers, toes and nose, but in severe conditions any area of skin which is exposed may equally be affected. *It is most important to* be on the look-out for the onset of this condition and regular inspections of areas of exposed skin should be carried out. At times when the ambient temperature may not be particularly low, it is still important to remember the danger of wind-chill as a cause of frostbite. Even short journeys out of doors should not be made without taking full precautions to prevent this insidious and hazardous condition.

20. The treatment of frostbite is directed toward the prevention of permanent damage to the affected tissues. Rapid re-warming of the frozen tissues should be carried out as soon as possible. The best way of doing this, is to immerse the frozen part in warm water at a temperature between 42°C and 45°C. Fortunately it is not necessary to have a thermometer, since that temperature range can be judged fairly accurately with the normal hand. The water feels hot, but not so hot that it would be uncomfortable during prolonged immersion. In the absence of a supply of hot water, the next best thing is to warm the frozen area against the skin of the axilla or groin; the affected part may be massaged gently to stimulate the circulation, but on no account should it be rubbed vigorously with snow or ice.

TABLE 3

WIND-CHILL EFFECT

DRY BULB TEMP °C	LITTLE DANGER UP TO THESE WIND SPEEDS	DRY BULB TEMP °C	INCREASING DANGER AT THESE WIND SPEEDS	DRY BULB TEMP °C	GREAT DANGER ABOVE THESE WIND SPEEDS	DRY BULB TEMP °C
–10	< 20	–10	20 – 45	–10	see	–10
–15	< 10	–15	10 – 45	–15	previous	–15
–20	< 5	–20	5 – 45	–20	column	–20
–25	< 5	–25	5 – 30	–25	> 30	–25
–30	0	–30	0 – 20	–30	> 20	–30
–35	see	–35	0 – 10	–35	> 10	–35
–40	next	–40	0 – 10	–40	> 10	–40
–45	column	–45	0 – 5	–45	> 5	–45
–50		–50	0 – 5	–50	> 5	–50
DRY BULB TEMP °C	LITTLE DANGER UP TO THESE WIND SPEEDS	DRY BULB TEMP °C	INCREASING DANGER AT THESE WIND SPEEDS	DRY BULB TEMP °C	GREAT DANGER ABOVE THESE WIND SPEEDS	DRY BULB TEMP °C

NOTE: All wind speeds in knots
Based on maximum wind speed of 45 knots (22 m/s or 50 mph)

FORECAST DESCRIPTION OF WINDS:

45 knots = FRESH GALE
30 knots = MODERATE GALE
20 knots = FRESH BREEZE
10 knots = MODERATE BREEZE
5 knots = LIGHT BREEZE

PROTECTIVE MEASURES

21. There are a number of protective measures available to aircrew, whereby the hazards of thermal stress can be reduced, as follows:

(a) A MANY LAYERED FLYING CLOTHING ASSEMBLY and clothing with a high insulating quality, provide valuable protection against the effects of cold. They can, however, present problems at other stages of the flight should the cockpit temperature rise. In some cases, this has led to the necessity of supplying a layer of air, or liquid cooling next to the skin, by means of a suitable garment worn under the layers of clothing. This facility is particularly useful when rubberised garments are worn for protection against cold water immersion in the event of an emergency, (see Chapter 19).

(b) PROTECTION OF THE CREW COMPARTMENT from high ambient temperatures and the effects of solar radiation, whilst the aircraft is on the ground, is a useful means of reducing the heat load on the crew when they enter the aircraft. This can be done in a number of ways, depending on the size of the aircraft and equipment available. Sun screens over the cockpit transparencies and 'blankets' of insulating material placed temporarily around the outside of the cabin walls have been used. With or without these, a means of blowing cooling air into the cabin of a parked aircraft is also a valuable means of preventing the workspace becoming too hot.

(c) CABIN CONDITIONING is an essential feature of modern high performance aircraft; there are, however, two practical problems. Firstly, there is usually an insufficient source of cooling air from the engines when they are at near idling speed; secondly, aircraft systems frequently fail to meet the extra thermal load imposed by avionic systems, or kinetic heat during high speed low level flight. This has been further aggravated in many new aircraft by the need to supply large quantities of cooling air to onboard electronic equipment. These situations can only be overcome by some form of personal conditioning.

(d) PROTECTIVE CLOTHING is available to aircrew to meet the needs of the theatre and aircraft role – crews should be familiar with the equipment, ensure that it remains in good condition and use it effectively, (see Chapter 19).
(e) THE PREVENTION OF HEAT EXHAUSTION AND HEAT STROKE has already been mentioned in paragraph 13. A plentiful supply of water and adequate salt intake are essential when working in hot environments and unacclimatised personnel should be strictly supervised, to ensure that they are not so over-exposed to heat as to cause a failure of their thermo-regulatory system.

CONCLUSION

22. Ultimately, the question of protection from heat or cold, whether on the ground or in the air, comes back to the individual crew member. So much can be done by having a thorough knowledge of the problem, making full use of the protective devices supplied, careful planning and sound training.

- **THERMAL STRESS IS A COMMON AEROMEDICAL PROBLEM,**
- **UNACCLIMATISED INDIVIDUALS REQUIRE STRICT SUPERVISION.**
- **AN UNDERSTANDING OF THERMAL STRESS PROVIDES PREVENTIVE INFORMATION.**
- **ENSURE AN ADEQUATE INTAKE OF WATER AND SALT IN HOT AREAS.**
- **GUARD AGAINST WIND-CHILL EFFECTS IN LOW TEMPERATURES.**
- **KNOW YOUR PROTECTIVE MEASURES AND USE THEM ROUTINELY.**

CHAPTER 10

ACCELERATION

INTRODUCTION

1. Modern aircraft are highly manoeuverable and capable of flying at very high speeds. These performance characteristics mean that aircrews can be exposed to large accelerative forces. Speed itself in straight and level flight has no effect on the human body; acceleration, on the other hand, may produce very considerable effects. This chapter deals with the various types of acceleration which may be encountered in flight, their effects on the human body and how these may be minimised, so that aircrew can make the best use of their aircraft's capabilities.

TERMINOLOGY

2. It is useful to define the usual terminology before describing the various types of acceleration:

(a) SPEED describes the rate of change of position of an object and is expressed as distance covered in unit time.

(b) VELOCITY describes both the magnitude and direction of motion and is measured in distance per unit of time in a particular direction. The velocity of a body changes if it changes direction, speed or both.

(c) ACCELERATION is a change of velocity in magnitude or direction and is generally expressed in: m/s^2 (ft/s^2). The most familiar type of acceleration is that due to gravity which is a constant and has a value of: $9.8\ m/s^2$ ($32\ ft/s^2$). The force producing that acceleration is, for convenience, referred to as 1G and an acceleration of: $19.6\ m/s^2$ ($64\ ft/s^2$) would be 2G, since force and acceleration are proportional.

TYPES OF ACCELERATION

3. There are three types of acceleration which are encountered in flight, namely; linear, radial and angular:

(a) LINEAR acceleration results from or produces an increase in the rate of progress along a straight line and is experienced in an aircraft when speed is increased without change in direction. This type of acceleration is also encountered when speed is decreased although it is more correct to refer to this as 'deceleration'. Linear accelerations are also associated with: catapult or rocket take-off, crashes, crash-landings and ditchings, aerodynamic buffeting, seat ejection, parachute opening shock and landing. The amount of G applied during linear acceleration can be calculated from the following equation:

$$G_L = \frac{V_2{}^2 - V_1{}^2}{g \times 2S},$$

where: G_L = linear G force

V_2 = final speed (in m/s or ft/s)

V_1 = initial speed (in m/s or ft/s)

g = force of gravity (9.8 m/s^2 or 32 ft/s^2)

S = distance over which object accelerates (in m or ft)

(b) RADIAL acceleration occurs with any change of direction when travelling at a constant speed. It is, therefore, an acceleration caused by rotation about a distant axis and acts outwards from the centre of a circular path. For instance, in flight, radial accelerations are experienced in a turn, when pulling out of a dive or during a loop. The amount of G experienced during a turn can be calculated using the following equation:

$$G_R = \frac{V^2}{g \times r},$$

where: G_R = radial G force

V = speed (in m/s or ft/s)

g = force of gravity (9.8 m/s^2 or 32 ft/s^2)

r = radius of return (in m or ft)

(c) ANGULAR acceleration is complex and involves a change in both speed and direction simultaneously; the axis of rotation is either through or very close to the subject's body. This type of acceleration occurs about the fore and aft axis of an aircraft if, whilst altering direction, the aircraft is banked or rolled, as in a tight spin. The principal effects on the body are associated with the vestibular apparatus and will be discussed in Chapter 11, which deals with orientation in flight. Angular accelerations are measured in units such as degrees per second^2 or radians per second^2, but not in G units.

FACTORS THAT DETERMINE THE EFFECTS OF ACCELERATION ON MAN

4. The effects of acceleration on the body depend on the following factors:

(a) MAGNITUDE of the acceleration: in general, the greater the intensity the more severe are the effects of accelerative forces. Intensity alone is not the only factor, however.

(b) DURATION of acceleration is also important since it dictates whether or not there is sufficient time for physiological disturbances to occur, (see paragraphs 5 and 6). For example, if an aviator was exposed to 12G in a tight turn he would lose consciousness in about 2 seconds, whereas he could experience that level of G on landing, after jumping from a table, without suffering any ill effects at all.

(c) DIRECTION of an accelerative force with respect to the long axis of the body is important because it influences the physiological disturbances which can occur. For example, the onset of 'red out' or 'black out' depends upon whether the inertial accelerative force is headward or footward (see paragraph 8 and Table 4). Direction is also important in a crash deceleration because it determines whether or not the force will throw the person out of his seat.

(d) AREA AND SITE over which the force is applied to the body: the greater the area of the body over

which a given force is distributed, the less harmful the effects. The site of application is clearly significant because a given force applied to the head can be much more serious than the same force applied to other areas of the body.

(e) RATE OF APPLICATION can have a significant effect on the threshold of response. For example, it has been shown that the onset of 'blackout' is delayed if the acceleration is applied slowly. The rate of onset is also significant in whether or not injury occurs. For example, although two ejection seats might produce the same peak G forces, one could have a higher rate of application of G, thereby causing structural damage to the body. Man's tolerance to both peak G and rate of application of G or 'jolt' must be considered in defining the performance characteristics of ejection systems (see paragraph 13).

ACCELERATION OF LONG AND SHORT DURATION

5. Accelerations are conveniently divided into those of long or short duration because of the significance of the time factor in deciding the effects of acceleration on the body. Acceleration of relatively long duration, allows sufficient time for a significant fluid shift to occur within the body, thus the dynamics of the blood circulation can be affected. Accelerations of relatively short duration, usually less than a second, depend for their effects upon the magnitude and characteristics of the acceleration and the structural strength of the body (see paragraphs 10 to 16). The rate of onset (or jolt factor) is much more significant than in accelerations of longer duration.

6. In general, accelerations of short duration are more often associated with an emergency situation, such as during seat ejection, parachute opening shock or crash landing, whereas accelerations of long duration are experienced during routine aircraft manoeuvres, particularly steep turns and the pull-out from a dive.

DIRECTION OF ACTION OF G FORCE

7. It has already been pointed out in paragraph 2 that the effects of linear and radial accelerations are measured in G units. In effect the weight of an object changes during acceleration, since an additional gravitational field can be said to have been temporarily established. This force, which is additional to the earth's force of gravity, is an inertial force acting on the body and is equal and opposite to the accelerative force. (Newton's Third Law of Motion). For example, when an aviator is accelerated in a headwards direction, then, with respect to the long axis of his body, he experiences a reactionary force of inertia towards his feet. It is this inertial force, if it is sufficiently prolonged, which determines the physiological effects which occur.

DESCRIPTIVE TERMINOLOGY OF G FORCES

8. It has now been established that G forces are described by the direction and amount of the inertial force with respect to the long axis of the body. There is a form of terminology in common use which describes these inertial G forces simply and concisely. For example, the positive G experienced during pull-out from a dive is: $+G_Z$, where the suffix Z denotes that the force is acting along the line of the long axis of the body and the prefix + denotes that the inertial force is acting in a head-to-foot direction (positive G). In conversation, the more descriptive expression 'eyeballs down' is commonly used to describe the inertial force $+G_Z$. The various forms of acceleration, and the resultant inertial forces acting on the human body, are shown in Table 4.

EFFECTS OF LINEAR ACCELERATION

9. It was pointed out, in paragraph 3, that high values of linear acceleration may occur during rocket or catapult take-off ($+G_X$), in the conventional seated position, or as a decelerative force ($-G_X$) during a crash landing.

10. The human body, when properly supported, can tolerate very high levels of acceleration if the duration is sufficiently short. An acceleration of 40G has been experienced

experimentally without injury and 60G can be reached with survivable injuries. In practice, however, it is not usual to provide protection against accelerations higher than 25G since this figure would only be exceeded in uncontrolled crashes involving massive structural disintegration of the aircraft. For example, the linear acceleration experienced during catapult launch is approximately 4G and the deceleration associated with a wheels-up landing or ditching is of the order of 10 to 15G.

TABLE 4

ACCELERATION TERMINOLOGY

Direction of Acceleration of Body	Direction of Resultant Inertial Force	Physiological Description	Terminology	Conversational Description
Headward	Head-to-Foot	Positive G	$+G_Z$	Eyeballs Down
Footward	Foot-to-Head	Negative G	$-G_Z$	Eyeballs Up
Frontwards	Chest-to-Back	Supine G	$+G_X$	Eyeballs In
Backwards	Back-to-Chest	Prone G	$-G_X$	Eyeballs Out
To Your Right	Right-to-Left Side	Left Lateral G	$+G_Y$	Eyeballs Left
To Your Left	Left-to-Right Side	Right Lateral G	$-G_Y$	Eyeballs Right
Body Direction	Direction of Physiologically Significant Inertial Force			

11. Buffeting may be experienced during flight at high speed in turbulent conditions, particularly at low level, in hot climates and over uneven terrain. These rapidly alternating vertical accelerations are usually of the order of 1.5G to 2G but levels of up to 3G may occasionally be experienced in high speed flight. Buffeting hastens the onset of aircrew fatigue and can also result in injuries if an inadequate or loose seat harness allows crew members to be thrown against the cockpit canopy or cabin roof.

12. Since 'escape from aircraft' is dealt with in Chapter 16, only the accelerative aspects of seat ejection will be considered in this chapter.

13. In order to clear high tail structures and also to offer a low-level escape capability, the ejection seat gun has to provide the highest possible velocity without causing damage to the seat occupant. There is not only a limit to the absolute acceleration which can be used, but also to the rate at which this acceleration can be applied. The limit of human tolerance to ejection thrust is usually considered to be 25G with a maximum rate of rise of G of 300G per second. Ejection accelerations depend not only on the energy of the gun system but also on the transmission of energy from the seat to the man. It is essential therefore that no unauthorised equipment is placed in the seat-pan nor the characteristics of that equipment altered in any way, lest the maximum safe G levels are exceeded.

14. Following ejection, particularly at high indicated airspeeds, further accelerative forces will be experienced due to seat tumbling or the deployment of the seat stabilising equipment.

15. Because of the limits on ejection trajectories imposed by the maximum human tolerance to acceleration, rocket seats or rocket assisted seats have been developed as an alternative to the conventional gun systems. The advantage of rocket assistance is that it permits the application of thrust for a longer time, thereby achieving higher trajectories without exceeding or even reaching the limits of human tolerance.

16. High acceleration loads may be experienced during parachute deployment and the opening shock load increases with both airspeed and altitude. The higher the airspeed, the shorter is the time available for the parachute canopy to fill with air so the deployment is more rapid. Also, the parachute canopy opening is facilitated at high altitude because the air density is less. This decrease in deployment time increases the opening shock. For example, a parachute with an opening shock load of 8G at an altitude of 2 000 m (7,000 ft) would have an opening shock load of about 30G

above a height of 12 000 m (40,000 ft). An opening shock load of that magnitude would damage the parachute canopy and might also injure the user. This is one of the main reasons for carrying out a free-fall after high altitude bail-out (see Chapter 16 paragraph 24d).

PROTECTION AGAINST LINEAR ACCELERATIONS

17. Protection against the effects of linear accelerations is primarily associated with body posture and restraint. Even at low levels of deceleration ($-G_X$), the unrestrained occupant of a forward facing seat may be projected out of his seat and injured or killed by striking any solid object in front of him. It is clear, therefore, that the problems associated with high levels of acceleration of short duration are those concerned with effective body restraint. The conventional seat harness in an aircraft has both a lap-belt and shoulder straps. The restraint afforded by the lap-belt across the thighs protects against vertical accelerations and the shoulder harness against forward acceleration. Vertical restraint is greatly improved if the lap-belt is held down to the front of the seat-pan by a short connecting strap. It is essential that the seat-harness is well positioned around the body, correctly and firmly adjusted. A well-fitting and secure crash-helmet also provides useful additional protection in these circumstances. In the case of passenger-carrying aircraft, rearward facing seats for passengers are valuable because the whole seat and not just the harness, provides body restraint during a crash deceleration.

18. During vertical accelerations, associated with seat ejection, it is important to maintain a good posture, otherwise the spinal column might be damaged, (see Chapter 16, paragraphs 16 to 20).

GENERAL EFFECTS OF RADIAL ACCELERATIONS

19. Radial accelerations are those most commonly experienced in flying. The formula governing the accelerative force during curved flight has already been given in paragraph 3b. This shows that the acceleration varies with the square of the speed; so that doubling the velocity of flight in a curved path quadruples the accelerative force applied to the

aircraft and crew. The formula also shows that halving the radius of turn doubles the force.

20. The force which is exerted on the body is interpreted as an increase in weight and since weight equals mass x acceleration, the weight must increase directly with acceleration, since the mass remains constant. At a radial acceleration of + 4G a body is 4 times as heavy as at the normal + 1G of straight and level flight. The various types of inertial forces which act on the body have been defined in Table 4. The appropriate physiological effects of these inertial forces of long duration will now be discussed with particular reference to positive and negative G during exposure to radial acceleration.

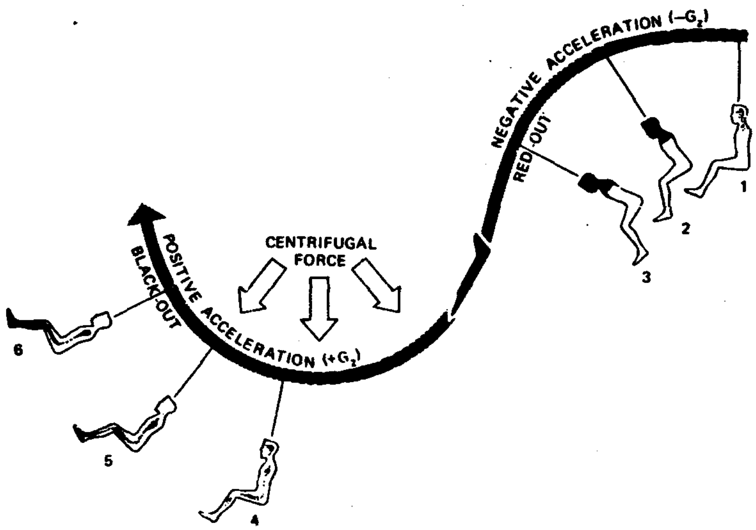
EFFECTS OF POSITIVE G ($+G_Z$)

21. Under conditions of excess positive G ($+G_Z$) the effective weight of the whole body is increased, as follows, (see Fig.11):–

(a) Loose body tissues are dragged down under the increased weight; this is most apparent in the skin of the face.

(b) Although the effective weight of the body may be many times greater, the power of the muscles remains the same and it becomes progressively more difficult to perform movements. For example, if the head is lowered, it may not be possible to raise it again; the limbs will be similarly affected. At $+2.5G_Z$ it is impossible to rise from the sitting position, making unaided escape from an aircraft very difficult indeed; at $+3G_Z$ it would be impossible.

(c) The blood becomes heavier, which lowers the blood pressure above the level of the heart whereas, below that level the blood pressure is increased and blood pooling occurs in the lower extremities. This failure of the normal return of venous blood to the heart reduces the supply of venous blood which is available for reoxygenation in the lungs, before subsequent redistribution round the body.



NEGATIVE ACCELERATION = FOOT TO HEAD

POSITIVE ACCELERATION = HEAD TO FOOT

RED-OUT ($-G_z$)
1 FACE FEELS FLUSHED AS BLOOD POOLS
2 VISION REDDENS AS $-G_z$ INCREASES
3 RED-OUT OCCURS (ABOUT $-3G_z$ FOR SOME SECS)

BLACK-OUT ($+G_z$)
4 LIMBS FEEL HEAVY WITH ONSET OF $+G_z$
5 BLOOD POOLS IN EXTREMITIES, VISION FADES (GREY-OUT)
6 BLACK-OUT OCCURS (ABOUT $+5G_z$ FOR 5 SECS)

Fig.11 Effects of Radial Accelerations

(d) The heart itself is displaced downwards by its increased weight, increasing the vertical distance from the heart to the head through which a column of blood, already heavier than normal, has to be maintained.

22. As a result of these circulatory disturbances, the eye and brain are temporarily starved of oxygen and partial loss of vision (grey-out) begins, followed, usually about +1G higher, by total loss of vision (black-out). This would eventually be succeeded by loss of consciousness if the manoeuvre was prolonged. The loss of vision begins on the periphery of the visual field and gradually spreads into the centre; the grey-out phase can be likened to looking down a foggy tunnel. These visual disturbances occur before consciousness is lost, because the retinal vessels cannot overcome the internal pressure within the eye, although the blood pressure is still adequate to support brain function.

23. As in many other situations, the body makes some attempt to compensate for these difficulties. For example, if grey-out is experienced during a constant turn, vision will improve even though the accelerative forces remain unchanged. This is due to a reflex constriction of the peripheral blood vessels in the limbs and trunk so that more arterial blood can be made available to supply the head.

24. The severity of these effects depends upon the duration of exposure as well as the magnitude of the acceleration (see paragraph 4), thus both of these factors must be defined when describing the body's response to radial acceleration. A force of $+3$ to $+4G_Z$ acting for 3 seconds causes constriction of peripheral vision and at $+4$ to $+5G_Z$, acting for a period of 5 seconds, grey-out and eventually black-out are likely to occur. Personal G tolerance will be adversely affected by a number of factors such as hunger, alcohol, excess smoking, recent illness, fatigue and hypoxia.

25. The effects of blacking-out disappear almost as soon as the G level is reduced, although the individual may be confused for a few seconds and have some difficulty in focusing his eyes. Following unconsciousness however, there may be a period of mental confusion lasting up to 30 seconds. For

this reason $+G_Z$ acceleration should not be applied beyond the black-out stage and extra care should be taken if the aircraft handling is critical around black-out threshold. During the recovery phase, involuntary twitching and jerky limb movements may occur; these are not significant and leave no after-effects of any kind.

FACTORS THAT INCREASE TOLERANCE TO $+G_Z$

26. Since the serious consequences of high positive G levels are due to adverse effects on the circulation, it follows that efforts to support the circulation will increase an individual's G tolerance. This can be achieved in three ways:

(a) BODY POSITION – A suitable alteration of posture can reduce the heart to brain distance, thereby reducing the height through which the blood has to be pumped to provide an adequate blood supply to the brain. A reduction of the vertical distance between the heart and eye of 9 cm (3.5 in.), by adopting a crouched position, can increase a seated person's G tolerance by nearly 1G. A change in posture which reduces the tendency for blood to pool in the lower limbs also helps by increasing the volume of circulating blood. Aircraft have been designed in which the pilot was placed in a prone or supine position, but in conventional aircraft the advantages have usually been outweighed by design difficulties and lack of external view. In spacecraft, however, the supine position is preferred during the launch and recovery phase.

(b) VOLUNTARY MANOEUVRES – There are various voluntary manoeuvres which an individual can perform in order to improve his G tolerance. The principle underlying these manoeuvres is to raise the pressure in the abdominal cavity, so as to maintain the level of the diaphragm and facilitate the return of venous blood to the heart. This is usually achieved by tensing the abdominal muscles and straining or shouting. It is essential that these actions are intermittent since to sustain an increased intra-abdominal pressure by continuous straining would have an adverse effect and lower the G threshold. It is also useful to promote the

return of venous blood up the legs and back to the heart, by intermittently tensing the leg muscles. Many aircrew use the M-1 manoeuvre which combines many of these techniques and is effective in raising G tolerance by about 1–1.5G. It consists of bending the trunk forward at the hips to achieve postural protection and at the same time contracting the abdominal and chest muscles and expelling the breath slowly. Respiratory cycles are repeated every 5 to 10 seconds. In order to achieve improved venous return, the arm and leg muscles are tensed simultaneously. Experienced aircrew carry out many of these practices automatically and indeed subconsciously; this is one of the reasons why they may have an apparently higher G tolerance than the less experienced.

(c) ANTI-G SUITS – are now standard equipment in aircraft where high G levels are experienced, (see Chapter 19). The object of the suit is to compress the major vascular bed below heart-level and help to maintain the level of the diaphragm. The operation is automatic and graded pressures are delivered to the bladders in the suit according to the level of G which is present. A gain in tolerance of +1.5 to +2G is usually obtained, when measured by the onset of 'black out'. Apart from raising the G threshold, the anti-G suit also reduces fatigue when numerous high G manoeuvres are performed.

NEGATIVE G ($-G_Z$)

27. When the resultant of centrifugal force and gravity is directed towards the head, as in a bunt (outside loop), the body is exposed to negative ($-G_Z$), (see Fig.11). This is both unpleasant and dangerous at far lower numerical values of G than when the acceleration is from head to foot ($+G_Z$). As soon as an aircraft is inverted its occupants experience −1G and any added negative acceleration causes blood to be forced into the head and neck. The face becomes congested and the field of vision may be covered by a red mist, known as a 'red-out'. The unsupported blood vessels on the surface of the eyes may become ruptured due to congestion and

like any other kind of bruise this redness takes many days to clear. The limit of tolerance to negative G, lasting for some seconds, is about –3G. Higher levels than this produce symptoms which are rather similar to concussion. As yet there is no standard method or equipment, in use in any air force at the present time, for providing protection against $-G_Z$, but the $-G_Z$ levels normally experienced in operational flying are well within safe limits. The problem tends to become more significant during aerobatic demonstrations.

TRANSVERSE G ($+G_X$, $-G_X$)

28. Transverse G acts through the body from chest to back or vice versa. When the inertial or centrifugal force acts in a plane which is perpendicular to the long axis of the body the circulation and its hydrostatic pressures are not particularly affected. Thus, the usual symptoms which would occur in $+G_Z$ acceleration do not occur in the $+G_X$ situation. The main difficulties with this type of acceleration are associated with respiration. At levels above $7G_X$ breathing becomes increasingly difficult because of the effect on chest movement, but some individuals can withstand levels of $20G_X$ for several seconds with no severe difficulty.

LATERAL ACCELERATION ($+G_Y$, $-G_Y$)

29. Lateral accelerations are only occasionally encountered in flight, for example during spinning manoeuvres and they are unlikely to be sustained. These accelerations may also be experienced during crash landings when the G level would be higher but the duration of exposure is likely to be short.

CONCLUSION

30. Accelerations of long duration are experienced in flight in a variety of circumstances and can cause important physiological disturbances. Those of short duration are usually associated with an emergency situation and good posture and body restraint are the critical protective factors.

- ACCELERATIONS INCREASE WITH THE SQUARE OF THE AIRSPEED.
- ACCELERATIONS OF LONG DURATION CAN CAUSE CIRCULATORY DISTURBANCES.
- BLACKOUT THRESHOLD IS APPROXIMATELY $+5G_Z$ FOR 5 SECONDS.
- VOLUNTARY MANOEUVRES AND POSTURE CAN RAISE +G THRESHOLD.
- ANTI-G SUITS RAISE G TOLERANCE AND REDUCE FATIGUE.
- GOOD POSTURE AND BODY RESTRAINT PROTECT AGAINST SHORT ACTING ACCELERATIONS.

CHAPTER 11

ORIENTATION IN FLIGHT

INTRODUCTION

1. Orientation in flight refers to an individual's ability to appreciate his position relative to the earth's surface, which infers that he is aware of the attitude of his aircraft with reference to the horizon.

2. In flight, the problem of orientation is much greater than it is on the ground, because the body can be influenced by a variety of misleading impressions due to the accelerations imposed upon it by the aircraft motion.

3. The various sources of information whereby man is able to orientate himself on the ground will be discussed: followed by the effects of flight and the ways in which an aviator can orientate himself safely.

ORIENTATION ON THE GROUND

4. Man has three main sources of information whereby he is able to maintain his orientation with respect to the earth's surface namely, the eyes, the vestibular apparatus (organs of balance) and the skin and joint receptors.

(a) THE EYES – These are the most important organs of orientation in man since a clear picture of his surroundings enables him to appreciate attitude, movement and acceleration. Information from the visual picture is therefore usually sufficient for the human body to maintain balance and orientation.

(b) THE VESTIBULAR APPARATUS – The organs of balance are situated on each side of the head in the inner ear. Each is known as the labyrinth or vestibular organ and is made up of two principal parts: the semicircular canals and the sac-like structures, the utricle and saccule, which contain the otolith organs, see Figure 12.

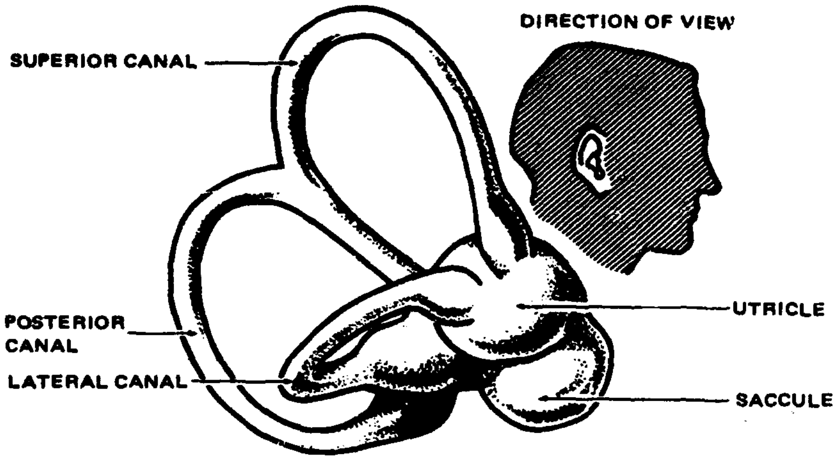
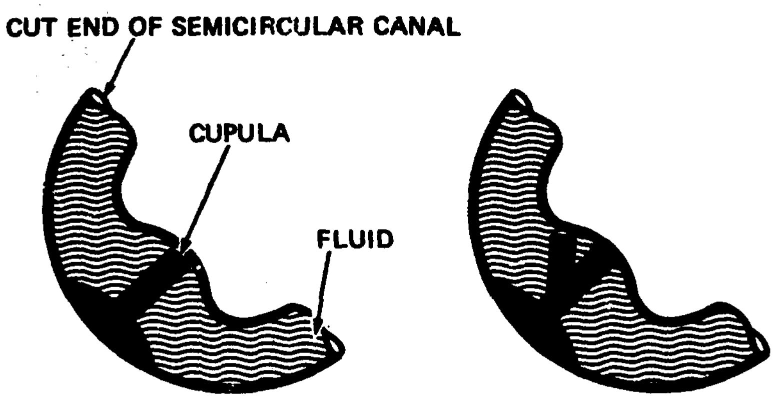


Fig.12 Diagram of the Right Labyrinth

(1) SEMI-CIRCULAR CANALS – In each labyrinth there are three semi-circular canals, which contain fluid-filled ducts, disposed in planes at right angles to each other; these canal systems are mirror images of each other on each side of the head. The sensory receptors in the ducts of the semi-circular canals respond to angular accelerations (see Chapter 10, paragraph 3c). When an angular acceleration is applied to the head, the fluid within the ducts of the semi-circular canals in the plane of rotation lags behind because of its inertia and this stimulates the sensory receptors sending nerve impulses to the brain which indicate that angular motion is occurring. This is caused by the fluid deflecting a flap-like valve (the cupula) situated at the base of each canal, as shown in Figure 13. As long as angular acceleration continues, the cupulae remain bent. When the angular acceleration ceases, however, and a constant velocity is maintained the cupulae gradually return to their upright, resting positions. The semi-circular canal system, like any other sensory system, has a threshold of response.



(a) Stationary condition of the cupula 'at rest'.

(b) Deflection of the cupula due to fluid shift.

Fig.13 The Action of the Cupula

Thus angular accelerations of less than $1°/sec^2$ are unlikely to give rise to any sensation of turning.

(2) OTOLITH ORGANS – These are situated below the semi-circular canals (see Fig.12) in the fluid filled sacs of the utricle and saccule. The otolith organs are made up of sensitive hairs tipped with small crystals and they respond to the magnitude and direction of gravity by virtue of the fact that the 'hairs' bend under the weight of these small crystals. As the head position relative to gravity is changed so is the pattern of bending of the sensory hairs. From signals transmitted to the brain, the position of the head with respect to gravity is derived. The otolith organs are sensitive to linear accelerations imposed upon the head in addition to the gravitational acceleration. Thus the sensory signals which they generate are the resultant of the earth's gravitational force and any applied linear acceleration.

(c) SKIN AND JOINT RECEPTORS – The stresses which are imposed upon the human body by accelerations cause flexion of the joints, alteration in muscle tone, stretching and twisting of tendons, skin and other tissues. These effects are picked up by nerve endings in the tissues and the information is relayed to the brain to indicate the changing forces acting on the body. This supplements the more precise information provided by the specialised sense organs of the vestibular apparatus.

5. These three main sources of sensory information provide the human body with information which, under normal circumstances, allows the brain to assess balance and orientation.

ORIENTATION IN THE AIR

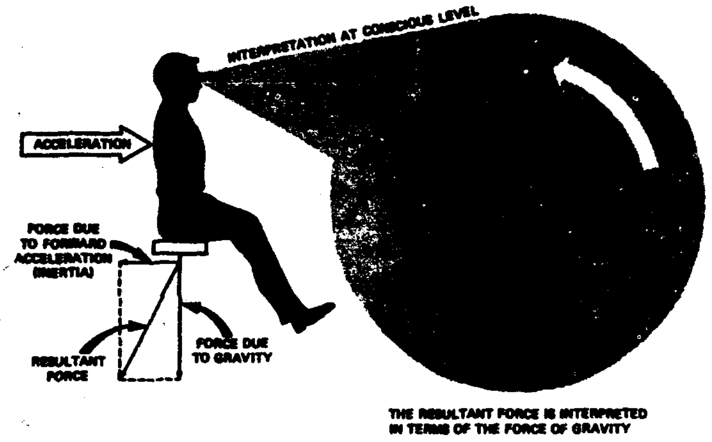
6. In flight, the problem of orientation is greater since the body can be affected by a variety of accelerations which, in comparison with experience on the ground, act in unfamiliar combinations and patterns. Of the three sources of orientation information which have been described, only the eyes can be relied upon to provide a true picture of the body's attitude in space, on condition that they receive adequate information from the outside world or an instrument presentation. The organs of balance and other receptors, on the other hand, are not only unreliable they are likely to pass information to the brain which is actively misleading.

7. There are a number of visual illusions which must be considered and these will be dealt with separately in paragraph 10c. They are related to a situation in which the visual picture of the outside world is inadequate; recourse to an instrument presentation overcomes these difficulties. There are two types of misleading sensation which arise in the organs of balance, namely misleading gravity sensation associated with the otolith organs and misleading sensations of rotation originating in the semi-circular canals.

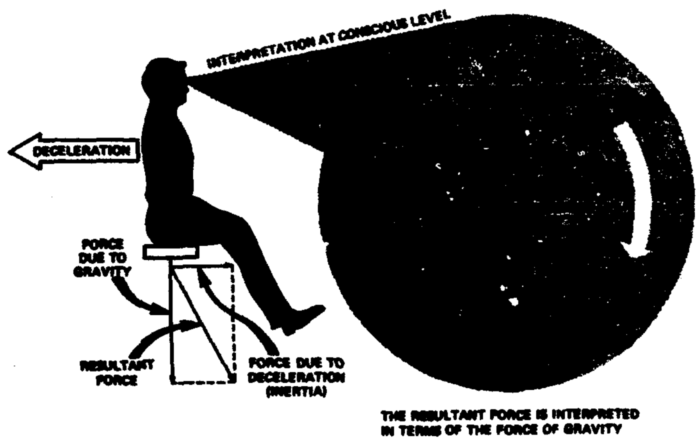
(a) MISLEADING GRAVITY SENSATION – At rest or at constant speed the only force acting on the otolith organs is that due to the earth's gravitational field. This

is constant both in magnitude and direction and any change in that force field is interpreted, through the otolith organs, as a variation of the gravity sensation. Thus resultant forces which are very different in magnitude and direction from that of gravity are wrongly interpreted at a conscious level. During a forward linear acceleration, for example, there exists the force of gravity acting downwards (body weight) and also an inertial force, associated with the forward acceleration, which can be considered as pushing the pilot back in his seat, (eyeballs IN or $+G_X$, see Chapter 10, Table 4). These two separate forces are interpreted as a single resultant force tilted backwards from the vertical. The mind continues to think of this resultant force as being vertical; producing at conscious level a false impression of the aircraft pitching up, (Fig.14a). During a sudden deceleration the opposite illusion is created (see Fig.14b). If the pilot acted on these sensations it could cause an accident, (e.g. pushing stick forward during overshoot).

(b) MISLEADING SENSATIONS OF ROTATION – It has already been shown in Figure 13 that, during rotation, the cupula in a semi-circular canal is deflected by the inertia of the fluid within the canal and registers changes in the rate of rotation. During prolonged rotations, however, when a constant angular velocity is reached and maintained, the relative movement of fluid in the canal disappears and the natural elasticity of the cupula causes it to return to its resting position (see Fig.15). Thus, although the body may be turning at a high rate there is no longer any information about rotation coming from the semi-circular canals. When rotation does eventually cease, the fluid in the canals surges in the direction opposite to that which was experienced initially, deflecting the cupula as it does so. The apparatus is now registering a rate of turn equal and opposite to that which was taking place and which has just stopped. The aviator has therefore experienced two misleading sensations; firstly, a lack of turning sensation during a steady turn and secondly, a feeling of turning immediately after the turn has stopped.



(a) The effect of acceleration causing a false sensation of 'pitch-up' change in attitude.



(b) The effect of deceleration causing a false sensation of 'pitch-down' change in attitude.

Fig.14 Oculogravic Illusion

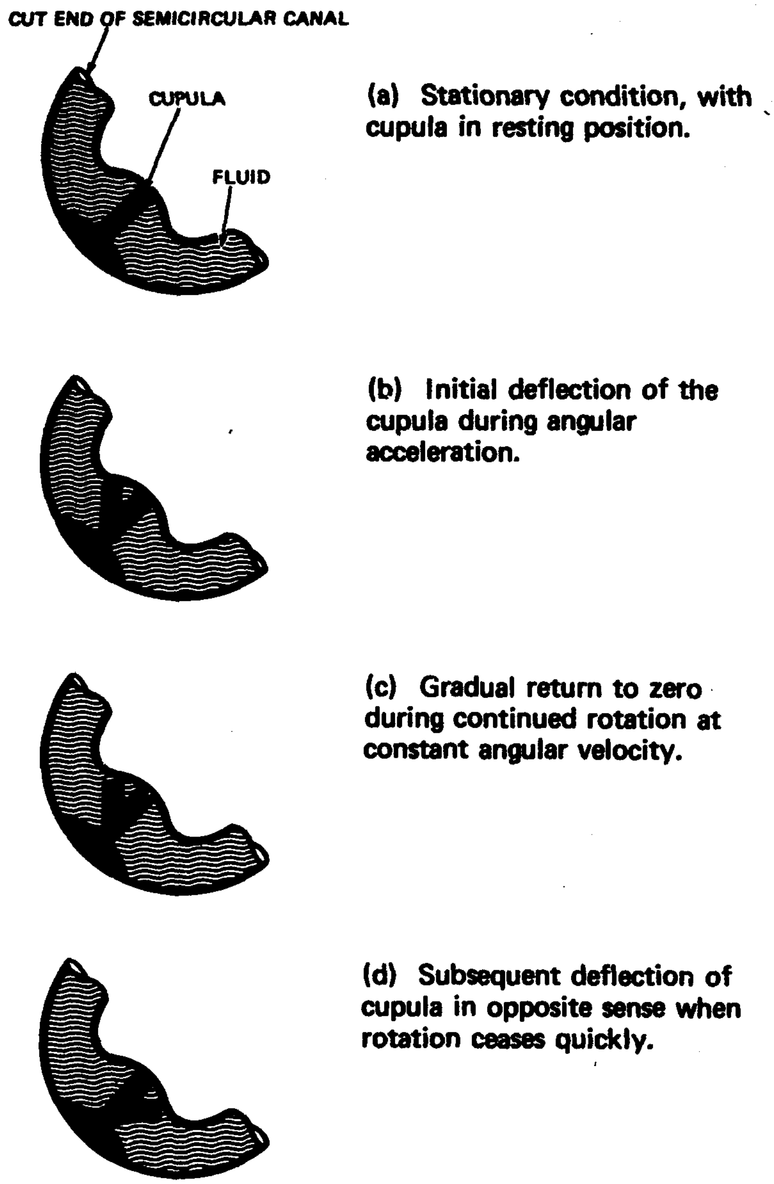


Fig. 15 The Action of the Cupula During Prolonged Rotation

8. These vestibular inaccuracies and errors in the sensing of both linear and angular motion can occur in varying degrees and in all three planes. In addition, if an aviator carries out angular movements of the head at the same time as his aircraft makes angular movements the semi-circular canals are stimulated in a more complex manner (Coriolis stimulation). This gives rise to bizarre and illusory sensations of turning with a component in a plane which does not correspond either with the angular motion of the head or the aircraft.

9. It is important that the reader does not get these facts out of proportion. The reactions represent the normal function of these organs and occur because the linear and angular accelerations to which man can be exposed in flight are of a differing magnitude and duration to those which are normally experienced during body movement on the ground. This means that all aviators will experience some misleading sensations sooner or later, in these circumstances. In visual flight conditions, where the ground and horizon are visible, there is little difficulty in ignoring false information from vestibular and other receptors since there are strong accurate impressions reaching the brain from the eyes. Where the visual cues are inadequate, however, these misleading sensations assume greater importance and can give rise to a state of conflict in the mind, since there will be sensory incongruity between them and the visual information. When this occurs, an individual is said to be suffering from disorientation. There are a number of situations which can precipitate this potentially hazardous state of mind and it is useful for the aviator to be aware of these. This forewarning prepares him so that he can take the appropriate corrective action and ignore them. In particular, he will always have recourse to his instrument presentation, which will provide a reliable visual information again, and he will thereby be able to suppress misleading cues.

FACTORS CONTRIBUTING TO DISORIENTATION

10. The situations which have been known to cause difficulty in maintaining orientation are as follows:

(a) INSTRUMENT FLYING – During instrument flight, particularly in haze, a pilot is continually cross-referring between his instrument presentation and the outside world, either to pick up another aircraft or a ground position. During the time which is spent looking into the hazy outside world, the eyes receive minimal reliable information on which to form an impression of the aircraft's attitude in space. During that time the vestibular apparatus and the skin and joint receptors are continually feeding the mind with orientation information which may well be erroneous because of the limitations of these sense organs. When the aviator looks back at his instrument panel he may then see a presentation which is different from the 'picture' which had been formed in his mind. At that moment, there is a state of conflict. The pilot who understands the problem however dismisses, almost without thinking, the misleading sensations and reacts to his aircraft instruments alone. The inexperienced pilot could, at this point, lose confidence and become disorientated.

(b) NIGHT FLYING – At night, groups of lights can give false impressions of attitude which are at variance with the instrument picture. On a very dark night, when there are no stars or horizon, the problem is similar to that which has been described when flying in haze and indeed may even be worse if the cockpit illumination is very low. The visual cues from any source are minimal and the information from the organs of balance and the skin and joint receptors impinge on the conscious mind quite strongly. This can be overcome by increasing the intensity of the cockpit lighting thereby re-orientating with familiar surroundings.

(c) VISUAL ILLUSIONS – There are occasions when the visual picture can be misleading and it is important to be aware of these circumstances:

(1) AUTOKINETIC ILLUSION refers to the apparent movement which a small static light source exhibits when stared at for a long enough time in darkness, particularly in situations where there is little other information. It is not related to aircraft movement, rather, it is seen as a random erratic movement of the light around a mean point. It is possibly due to tension of the observer's neck muscles and can best be overcome by moving the eyes about rather than staring fixedly at a single point light source. It also helps to increase the cockpit lighting where possible and in formation flying, for the lead aircraft to display navigation or formation lights if this is permissible.

(2) OCULOGYRAL ILLUSION is defined as the apparent movement of an object in the visual field, resulting from stimulation of the receptors in the semi-circular canals by angular acceleration. It is associated with the involuntary flicking of the eyes produced by signals from the semi-circular canals though it is perhaps better to consider this visual illusion as an extension of the illusory sensations of bodily motion to the visual environment. For example, when the body is rotated to the left, the target appears to move rapidly to the left, then gradually becomes motionless or may even appear to move very slowly to the right. When the rotation is constant and prolonged, the target appears motionless. When rotation is suddenly stopped, the target object apparently moves rapidly in the opposite direction (i.e. to the right in this example) and may not come to rest for many seconds. The magnitude of the illusion is related to intensity of the angular stimulus but is also affected or modified by circumstances. Thus, in broad daylight, it would only be noticed with large changes in angular velocity whereas at night it may be apparent with quite weak stimuli; individual experience also reduces the effect. Reference to aircraft instruments will confirm that this sensation is false.

(3) OCULOGRAVIC ILLUSION has been defined as a perception of tilt induced by stimulation of the otolith organs by linear acceleration and has already been described in paragraph 7a (see also Fig.14). This name should really be confined to the visual illusion which is characterised by an illusory impression that an object is moving up or down (according to the direction of the inertial force) in relation to the horizon. The aviator should refer to his instruments to gain the correct attitude indications and act accordingly.

(d) FORMATION FLYING – During formation flight, a pilot keeps station, and so remains orientated in relation to the constantly changing datum of the lead aircraft. He is therefore unable to maintain an updated and reliable mental picture of his orientation in relation to the earth's surface and it is common to experience a strong impression which is at variance with his true attitude in space. These false impressions are strongest during violent manoeuvres, particularly in restricted visibility. Formation leaders should bear this fact in mind and try not to add further distractions by calling for system selections at the same time as carrying out changes of power or direction.

(e) HIGH ALTITUDE FLYING – The problems associated with haze and glare at high altitude are discussed in Chapter 14, which deals with vision. Aviators should also bear in mind that owing to the curvature of the earth, the actual horizon as seen from an aircraft becomes progressively depressed below the horizontal as altitude increases. At very high altitudes, a considerable part of the sky becomes visible below the horizontal. This can lead to confusion if the aviator forgets that some stars (and the moon) can be seen beneath the aircraft. It also means that at these altitudes, if one wing tip is aligned with the horizon the other will be considerably above it.

(f) MANOEUVRES INVOLVING RAPID RATES OF ROTATION – On completing manoeuvres involving rapid rates of rotation, aircrew are likely to have strong

residual sensations of rotation, particularly at night (oculogyral illusion) and must concentrate on the instrument presentation to overcome them. These false impressions will be made worse if head movements are carried out during the manoeuvre (see paragraph 8). For example, the after-effects following spin recovery will be less confusing if the eyes are directed towards the horizon throughout the spin and not at the ground immediately below the aircraft since on the return of the aircraft to the horizontal the alteration of the plane of the head will be less. This does not mean that pilots should not look at their instruments during spin recovery; it simply infers that the maximum use of eye movements should be made in order to minimise major head movements.

(g) RAPID PRESSURE CHANGES IN THE MIDDLE EAR – Stimulation of the semi-circular canal receptors can be caused by sudden and large pressure changes in the middle ear, during ascent or descent. The dizziness and disorientation, termed 'pressure vertigo', which can be produced, is not very common but is a further reason for not flying when the ears cannot be cleared satisfactorily, due to congestion of the Eustachian tubes because of a head cold or similar infection.

(h) AFTER-EFFECTS OF ALCOHOL – The immediate effects of alcohol on the ability to orientate are well known. After heavy drinking, however, an individual may be left with after-effects for many hours and these can upset his ability to orientate, particularly during instrument flying. This is only one of the many reasons why flying and alcohol do not mix.

PREVENTION OF DISORIENTATION

11. Many of the preventive measures have already been mentioned. Perhaps the most important single factor, however, is the realisation that these misleading sensations are perfectly predictable and can happen to anyone, since they are due to the normal function and limitations of the organs of balance. Disorientation only becomes dangerous when the sensory incongruity causes mental conflict which is so

great that an individual is unable to bring himself to trust his instruments. Awareness of this potential hazard means that aircrew who experience these sensations in the air both understand their significance and know how to overcome them.

12. A high standard of instrument flying creates a relaxed pilot who will not be confronted with mental conflict in these situations; this comes with regular practice and a thorough knowledge of the aircraft and all instrument procedures. A pilot who has achieved this high level of performance will be able to scan his instruments efficiently and in a relaxed manner and be able to keep his mind up-dated on the attitude and performance of his aircraft. *He will not make the mistake of fixating on one instrument* and also if an instrument fails he will notice this immediately and deal with the situation without fuss or panic.

13. The first few flights on return to flying after a lay-off can be particularly hazardous. Following tours of ground duty, a planned and supervised re-training programme is therefore a normal requirement for all aircrew. Even after short periods of time away from flying, following leave or illness, aviators should take extra care until fully competent and back to regular instrument flying practice once again.

CONCLUSION

14. The eyes provide an aviator with his most reliable source of information about his attitude in space; flying by 'the seat of the pants' is notoriously misleading and dangerous. Awareness of the conflict which can occur, between the true visual picture and the effects of misleading orientation information at conscious level, serves to *remind the aviator of the importance of relying on his instruments.* This understanding, together with a well-founded confidence in his ability to fly his aircraft on instruments under all conditions of flight, produces a relaxed, efficient and safe aviator.

- **A CLEAR VISUAL PICTURE PROVIDES STRONG ORIENTATION CUES.**
- **FLYING BY THE 'SEAT OF THE PANTS' IS DANGEROUS.**
- **TO EXPERIENCE MISLEADING ORIENTATION SENSATIONS IS NORMAL.**
- **THE HAZARD OF DISORIENTATION IS PANIC RESULTING FROM SENSORY INCONGRUITY.**
- **IF WHAT YOU 'SEE' IS DIFFERENT FROM WHAT YOU 'FEEL' RELY ON INSTRUMENTS.**
- **SAFE EFFECTIVE FLYING MEANS A RELAXED PROFICIENT INSTRUMENT PILOT.**

CHAPTER 12

AIRSICKNESS

INTRODUCTION

1. Airsickness is brought about by aircraft motion and is characterised by nausea and malaise. This type of condition is also associated with other forms of motion, for example, car sickness, seasickness and swing sickness.

2. Many aircrew trainees suffer from airsickness, particularly in the early stages of training. It is natural to be distressed by this condition but those who are airsick should be reassured by the fact that they are in the majority and, like their predecessors, will overcome it as they learn to relax and to have confidence in their ability to succeed.

SYMPTOMS OF AIRSICKNESS

3. There are numerous signs and symptoms associated with airsickness as follows:

(a) Apathy
(b) Headache
(c) Stomach awareness
(d) Pallor
(e) Perspiration
(f) Nausea
(g) Vomiting
(h) Prostration

4. Although the symptoms of airsickness commonly occur in that sequence, this is not always so and individuals vary in their response to this condition. Certain people experience many of these effects, feeling ill for a considerable period of time, but they may not actually vomit; others have a relatively short warning period, vomit and feel better almost immediately.

5. As far as an aviator is concerned, the particular symptoms are not significant in themselves. It is the effect that they have on his ability to concentrate and to carry out his task which is important. Vomiting may have special significance if it has a humiliating effect as this is liable to slow up recovery. The adverse effects of airsickness on aircrew performance are not only important because they waste training time, they also make it difficult for an instructor to assess a student's true flying ability. If an individual feels mildly unwell, but keeps his symptoms hidden, his poor performance in the air may be attributed to a fundamental lack of skill or potential.

INCIDENCE OF AIRSICKNESS

6. It is difficult to get an accurate figure for the incidence of airsickness, and indeed for any type of travel sickness, because there is a natural tendency for some people to suppress the information; this is particularly so when applying for flying training. A recent survey showed that about 60% of aircrew trainees had suffered from some form of motion sickness prior to entry into the service. This suggests that the incidence in the population as a whole is probably very much higher than 60%, since those who are very susceptible to motion sickness would probably avoid this type of career.

7. The survey also showed that 24% of pilot trainees suffered from mild airsickness during their basic flying training and that a further 14.6% of trainees experienced airsickness which was sufficiently severe to interfere with their flying training progress at some stage.

8. The value of these figures is that they show that airsickness is a very common complaint. It is also important to realise that the vast majority overcome it and have a successful flying career. This knowledge should allay the doubts or fears of future trainees.

CAUSES OF AIRSICKNESS

9. Although the mechanism has not yet been determined with absolute certainty, it is clear that changing acceleration

acting on the labyrinth of the inner ear is a basic cause (see Chapter 10, paragraph 3c). This is indicated by two observations; firstly, that the incidence and severity of airsickness is closely related to the duration and severity of these accelerations and secondly that individuals without functioning labyrinths are immune to this condition.

10. This is not the whole story because, in the early stages of airsickness, aircrew are likely to develop some degree of anxiety about their problem. This is a natural reaction, particularly for someone who is hoping to make his career in aviation. There is yet another explanation for sickness in the air which may not be directly related to either of these two previous causes. This concerns the individual whose nausea is a manifestation of some form of anxiety or tension; being unrelated to aircraft motion it does not fall within the classical meaning of the term motion sickness.

11. It is convenient to categorise and examine these three causes of airsickness as: physiological, physiological with psychological (anxiety) overlay, and purely psychological.

(a) PHYSIOLOGICAL ASPECTS OF AIRSICKNESS – The function of the labyrinths has already been described in Chapter 11. Head movements during aircraft accelerations predispose to airsickness because of the relatively great angular accelerations imposed on the semi-circular canals due to the short radius of rotation of the head. Furthermore, movement of the head during aircraft rotation can bring different pairs of semi-circular canals into operation, resulting in a sudden rapid disturbance of the fluid within these canals, (see Chapter 11, paragraph 8). This causes a marked deflection of the displacement sensing cupulae in these canals, producing a strong feeling of rotation at conscious level. With experience however, aircrew adapt to the types of acceleration associated with their particular aircraft and flight manoeuvres. This process of adaptation to a new motion environment is similar to the experience of mariners who gain their 'sea-legs' after a few hours or days at sea. However, if an aviator goes to sea (or a sailor flies) the different characteristics

of the force field in the environment will once more reach his conscious level and he will have to get used to this new pattern of movement. The picture is further complicated by the fact that a change from one type of vehicle to another and in particular, one way of life to another, may introduce some insecurity so that psychological factors may come into play.

(b) PSYCHOLOGICAL FACTORS IN THE CAUSATION OF AIRSICKNESS – The psychological aspects of airsickness are very variable but they will be conveniently discussed under two headings, namely; those which are secondary to the physiological (vestibular) disturbance, and anxiety which in itself seems to be the primary cause of the sickness in the air:

(1) ANXIETY OVERLAY – This is caused by worrying about feelings of discomfort experienced during certain manoeuvres, or when exposed to a different mode of travel. The majority of people are likely to have experienced mild motion sickness at sometime in their past or will experience airsickness during their early flying training, so that the foundation of this anxiety is readily laid. It can manifest itself in different ways; an individual may associate his sickness with a certain aircraft type or a particular sequence of manoeuvres. This anxiety can slow up his ability to adapt to manoeuvres, such as spinning and aerobatics which are commonly associated with airsickness. It is important, therefore, to introduce trainees gradually to manoeuvres which provoke rapid changes in angular acceleration.

(2) PSYCHOLOGICAL FACTORS AS A PRIMARY CAUSE OF SICKNESS IN THE AIR – It is well known that certain individuals become tense before particular ordeals. This manifestation frequently occurs before academic examinations or interviews and in many cases reflects an individual's desire to do well in the challenge he is about to face. Such a situation can equally well occur in the air since learning to fly is also a challenge and one in which, particularly in the early stages, the individual's

performance is under the direct scrutiny of an instructor. It is understandable that some aircrew students will react to this challenging situation by feeling tense and nauseated. This type of 'tension sickness' will certainly be diagnosed as 'airsickness' but is not motion sickness, since it is not primarily associated with changing force fields. This type of sickness usually affects the conscientious individual who sets himself a very high standard but subconsciously cannot believe in his ability to achieve it. It has one important factor in common with the other psychological manifestation of airsickness, namely, a temporary loss of confidence.

PREVENTION OF AIRSICKNESS

12. Airsickness is prevented by acclimatising to the new environment and radial accelerations, by having a number of gentle and enjoyable flights at regular and short intervals. This is most important during early training. Whatever an individual's motion sickness history may be before he begins flying, he should not dwell on it when he starts his training. There is plenty of evidence to show that these people can learn to fly as well as any other and enjoy a full, unrestricted flying career.

13. The first few flights provide a new experience and introduce accelerations to which the trainee's vestibular apparatus may not have been exposed before. The outflow from this vestibular stimulus will certainly reach conscious level, so it is sensible to restrict both the magnitude and duration of exposure during early training. Trainees who have no previous flying experience benefit from gentle air experience flights before starting aerobatic manoeuvres.

14. Experienced aircrew are well aware of the fact that after a long period of duty on the ground violent manoeuvres may upset them. Refresher training is also carefully planned, so that high G manoeuvres are minimised during the early stages. In this case, however, the aircrew being experienced, are well aware of their personal limitations and

think nothing of them; whereas a student, through lack of knowledge of such matters, might be over-anxious about having to limit his flying because of airsickness.

15. There are other commonsense precautions which must be mentioned. An individual should not fly unless he feels fit and well. Recent illness, fatigue or the after-effects of alcohol all cause debility and adversely affect an individual's general ability in the air, (see Chapter 1). They also make him prone to airsickness particularly during violent aircraft manoeuvres.

TREATMENT OF AIRSICKNESS

16. Having described the causes of airsickness and the various methods of preventing it, there is very little to add concerning the treatment of the condition.

17. An individual who is suffering from 'tension sickness' will probably soon realise this if he analyses the kind of situation which nauseates him in the air and whether or not he has a tendency to be upset by problems on the ground. He will have to learn to live with his own high standards and realise that his sickness is a reflection of his personality and when he gets to grips with it, he will do very well as his tension disappears. His medical officer will always be willing to discuss the problem and help to reassure him that this is not by any means a sinister manifestation and is one which will be overcome quickly, once the mechanism is understood.

18. The commonest form of airsickness is a combination of psychological and physiological factors. At any moment in the history of an individual's airsickness both factors are likely to be present. The psychological overlay tends to become more significant as time passes because the individual becomes increasingly anxious about his ability in the air. Treatment consists of reassurance to help him accept the fact that he is no different from others; that he is 'normal' and that the sooner he realises this and adopts a confident outlook, the quicker he will overcome his airsickness. Trainees should discuss their airsickness, as early as possible, fully and frankly with their flying instructor. He will understand the problem and

make minor adjustments to the flying programme to help that individual adapt as quickly as possible. The instructor is also likely to consult the medical officer at some stage in order that the trainee is given the best help available. These are routine practices so the student need not feel that his treatment is exceptional.

19. There are a number of drugs which are available for the treatment of motion sickness. Unfortunately, all the effective ones can have side-effects, most of which are incompatible with safe and efficient performance in the air. These side-effects include: dryness of the mouth, sleepiness, dizziness and in a few cases serious visual disturbances which can include double vision. For these reasons, none of the drugs which are available for the treatment of airsickness are compatible with safe, efficient flying. Aircrew must never indulge in self-medication for their airsickness. In certain selected aircrew, a medical officer might decide to prescribe some form of medication. If so, this will be controlled most carefully and even then, will never be used when the trainee flies solo. Drugs have a useful place in the treatment of passengers, however, and the medical officer will advise accordingly.

20. Aircrew who are suffering from airsickness should try not to worry about the problem because anxiety will only inhibit adaptation. Early discussions will speed recovery and prevent misunderstanding when an individual's performance is decreased by the effects of airsickness. Under no circumstances should aircrew try to hide the condition by taking anti-motion sickness drugs. As well as being dangerous, this also further lowers confidence in the long run and together with a possible performance decrement produced by the drugs, will only make matters worse.

CONCLUSION

21. Although airsickness is common in the early stages of flying, the majority of aircrew students overcome it quite quickly with flying practice. This also applies to individuals who are returning to flying after a period of duty on the

ground. The time which is required for acclimatisation and the time taken to lose it again, during periods on the ground, are both very variable for different individuals. Experienced aircrew who become airsick on return to flying should not become despondent about this temporary set-back. By flying regularly and gradually training themselves in the manoeuvres which have given trouble, both inexperienced and experienced aircrew will soon find that the problem has been overcome.

- **MOTION SICKNESS IS DUE TO EFFECTS OF ACCELERATIONS ON THE VESTIBULAR APPARATUS.**
- **MAJORITY OF AIRCREW TRAINEES SUFFER SOME DEGREE OF AIRSICKNESS.**
- **VAST MAJORITY OF INDIVIDUALS ADAPT WITH PRACTICE.**
- **ASSOCIATED ANXIETY SLOWS UP NORMAL ADAPTATION.**
- **SELF-MEDICATION IS DANGEROUS, SEEK EXPERT HELP.**
- **SICKNESS IN THE AIR MAY REFLECT TENSION, LEARN TO RELAX.**

CHAPTER 13

NOISE AND VIBRATION

INTRODUCTION

1. Noise and vibration have been associated with powered flight from its beginning. The continual increase in power output to improve aircraft performance, has meant that these properties are no longer simply nuisance factors. High noise levels and severe vibration can have seriously detrimental effects on aircrew efficiency. In addition, any inability of crew members to communicate with each other or with ground stations because of noise, can jeopardise both aircraft and mission. In order to understand the effects of high noise levels on the ear, it is first necessary to examine the physical properties of sound and the main features of the hearing apparatus. These, together with sources of noise and vibration and various methods of protection, will be described in this chapter.

PHYSICAL PROPERTIES OF SOUND

2. The word 'sound' has come to be used to describe both a physical entity and the effect which it creates in the brain. This 'cause' or 'sound' is generated by an organised movement of molecules due to a body vibrating in some medium, such as air, water or solid. The 'effect' is a physiological sensation known as 'hearing', and is ultimately interpreted in the brain. These represent different aspects of a physical phenomenon created by the flow of energy from a given source to the organ of hearing, which takes the form of a wave of pressure passing through the appropriate conducting medium. In this chapter, reference will be restricted to the movement of sound waves through the medium of air.

3. The vibrations of a sound source cause it to push repeatedly against the molecules of air which surround it. These molecules, in turn, bump against their neighbours, then recoil to their original positions and the procedure begins all over again. This process radiates outwards as neighbouring

molecules affect each other, just as ripples in a pool spread when a stone is thrown into the water. The wave form progresses outwards although individual molecules never travel very far. This bumping and withdrawal of molecules causes momentary compression and rarefaction as the pressure wave moves through the air.

4. At any point in the path of the pressure wave there is, therefore, an oscillation of pressure and in the case of the simplest sound wave, this is a sine wave as is produced by a tuning fork. The main characteristics of a sound wave are therefore:–

(a) fluctuations of pressure above and below the ambient atmospheric pressure;

(b) frequency, which is the number of times each wave cycle is repeated each second (i.e. cycles per second or Hertz).

5. It will be seen when the physiology of hearing is discussed that the sound pressure and its frequency are significant measures of sound since the ear is a pressure-sensitive mechanism with particular characteristics. For instance, for a given sound, the greater the pressure fluctuations, the greater the degree of loudness registered.

ANATOMY AND PHYSIOLOGY OF THE ORGAN OF HEARING

6. The function of the hearing apparatus is to collect vibrations or sound waves in the air and convert them into nerve impulses for transmission to the brain. The ear consists of three main parts, the external or outer ear, the middle ear and the inner ear in which the organ of hearing lies. The pressure-sensitive tympanic membrane separates the middle ear from the outer ear, (see Fig.16).

7. Sound waves are collected from the surrounding atmosphere by the external ear and directed inwards toward the ear-drum, causing the tympanic membrane to vibrate. In the air-filled cavity of the middle ear and attached to the inner surface of the membrane is a chain of three small bones (ossicles) which magnifies these vibrations and conveys them to that part of the inner ear concerned with hearing. The

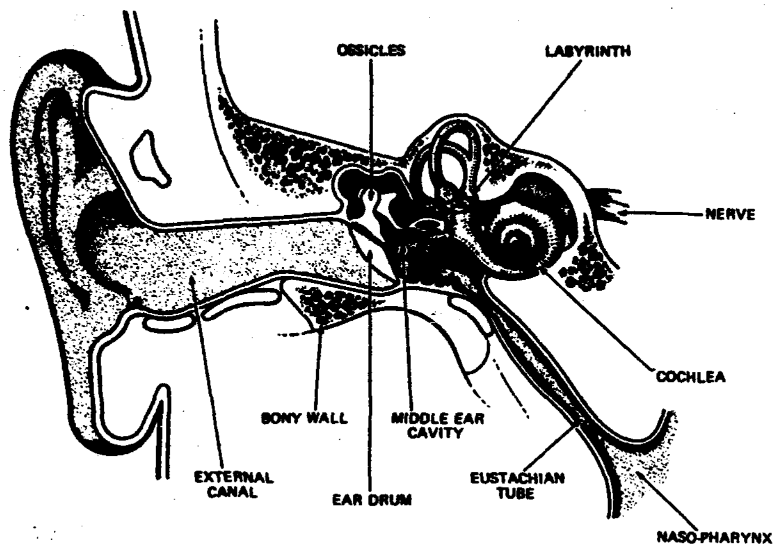


Fig.16 Structure of the Ear

cochlea, resembling a snail shell in appearance, is the organ of hearing which converts these vibrations into nerve impulses for onward transmission to the brain where they are perceived as sound. The remainder of the inner ear is concerned with the sense of balance, (see Chapter 11).

8. The total range of hearing in a healthy young adult extends widely in frequency from about 20 to 20,000 Hz. The most acute range of auditory response for the normal ear lies between 500 to 6,000 Hz, however and a 2,000 Hz tone represents a signal to which the ear is very sensitive.

TYPICAL NOISE LEVELS

9. Noise can be defined as a sound which is loud, unpleasant or unwanted. The levels at which noises become 'unwanted' will therefore vary very much with circumstances. Thus, coughing or paper rustling can be irritating and distracting in a concert hall or theatre but hardly noticeable in a city street. As noise intensities increase, however, they are not only a nuisance, but can be harmful.

10. The unit of measurement of sound intensity is the decibel (dB) which is a logarithmic function of the ratio of a particular sound pressure over a reference sound pressure. The standard reference pressure is very small indeed, being about the average pressure of the faintest sound which can be heard by young healthy people. A logarithmic scale is used to avoid large numbers since the range of sound intensities heard by the human ear is very extensive. This means that apparently small changes in dB levels represent large changes in sound pressure. Indeed an increase of 6dB would indicate a doubling of sound pressure.

11. The use of a logarithmic scale is particularly useful when discussing sound 'intensity' as distinct from sound 'pressure'. It can reasonably be assumed that sound intensity is proportional to the square of the sound pressure, so that a 10-fold increase in pressure represents a 100-fold increase in intensity. Thus, Figure 17, which gives the noise levels of certain familiar sounds in decibels can be interpreted as follows:–

1 dB = the least perceptible noise

40 dB (normal conversation) = 10,000 times the least perceptible noise

90 dB (on the factory floor) = 1,000,000,000 times the least perceptible noise

This also means that lowering sound intensity by a few decibels can make a significant improvement to comfort from the point of view of noise level.

AIRCRAFT NOISE

12. There are many major sources or contributors to the noise which is encountered in aircraft as follows:–

(a) The basic power plant – for example, 1% or more of the total power output of a jet engine can be in the form of sound, ranging from below the lower limits of audibility to ultrasonic oscillations;

(b) Rotating propellors and helicopter rotor blades;

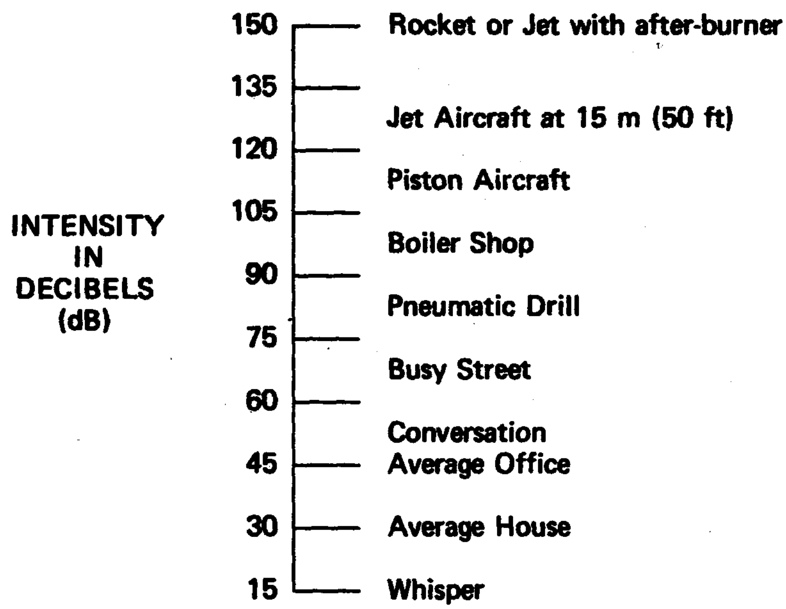


Fig.17 Noise Levels of Some Familiar Sounds

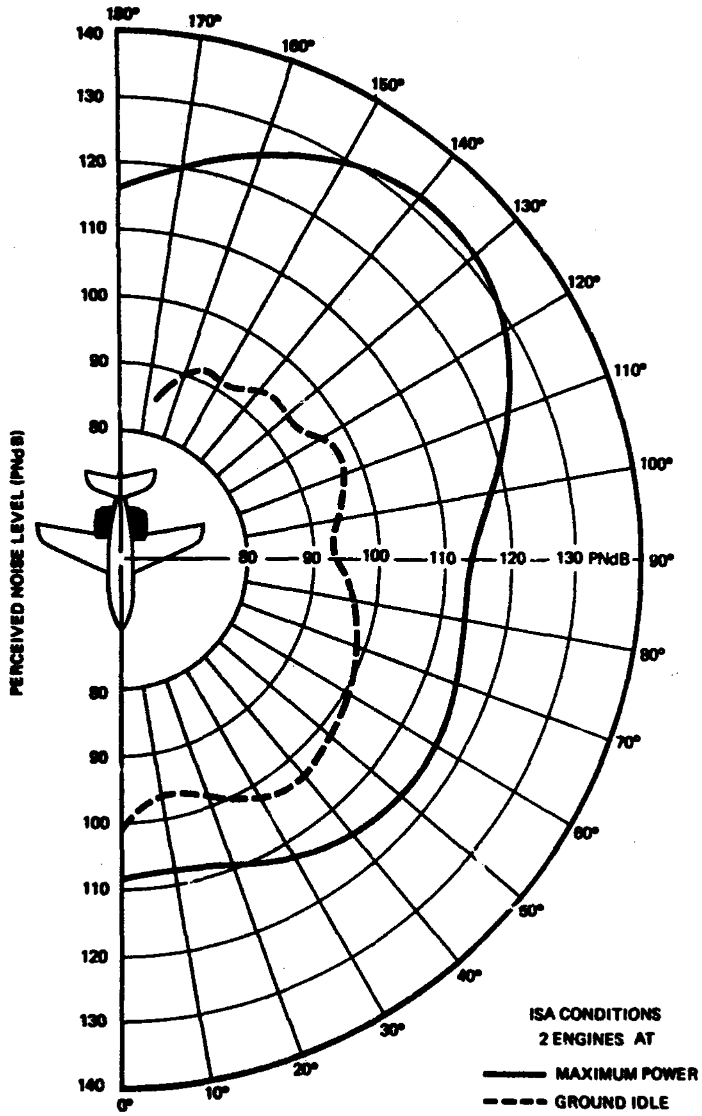
(c) Aerodynamic noise due to the friction of air over the fuselage and boundary-layer disturbances;

(d) Noise due to airflow in the pressurisation and air conditioning system;

(e) Noise emanating from power units in the avionics systems;

(f) Noise induced or aggravated by the communications system.

13. In modern jet aircraft some reduction in noise level is obtained because the cockpit is pressurised. (Type (a), (b) and (c) of paragraph 12). Nevertheless, the noise levels in some high performance aircraft can be sufficiently high to interfere with communication, particularly at high speed at low level and a great deal of research work is being carried out to overcome this. Also the problem of speech intelligibility in high background noise levels is being investigated with a view to improving voice communication systems.



Measurement of perceived noise levels showing maximum intensity at greatest distances about 40° from the tail of the aircraft.

Fig.18 Noise Contour Diagram

14. A knowledge of the pattern and direction of noise radiation from an aircraft is of great practical importance during ground handling. In general the maximum sound intensity is likely to be some 30° to 50° from the axis of the jet exhaust, (see Fig.18). Noise pattern data for specific types of aircraft are usually available for the guidance of ground crews.

15. The fact that aerodynamic noise contributes to the noise level in aircraft cabins has already been mentioned. At supersonic speeds, however, people on the ground can also be affected, due to shock waves from aerodynamic sources reaching the ground and causing 'sonic booms'. These shock waves are generated at both the front and rear of the aircraft, similar to the bow wave and wake of a ship and when they reach an observer on the ground his ears register a heavy double boom.

EFFECTS OF EXPOSURE TO HIGH NOISE LEVELS

16. The main effects of exposure to high noise levels can be attributed to their influence on an individual's health and well-being, but they can also adversely affect his ability to communicate in a particular noise field. Thus speech intelligibility will be considered as well as the injurious effects of noise. The severity of these effects depends upon the level and type of noise exposure, ranging from mild annoyance and irritation to permanent hearing loss. Interference with speech intelligibility can also be very serious in its own way because it can hazard mission completion and lead to aircraft accidents. These effects will now be examined with reference to various levels of noise exposure of increasing intensity:–

(a) FATIGUE, SLEEP LOSS AND ACCIDENT PRONENESS – Noise levels of modest intensity will not cause physical damage to the organ of hearing but nevertheless can have a detrimental effect on an individual's performance. Working in a noisy environment, whether on the ground or in the air, produces fatigue and irritation due to the need to exert greater concentration and can lead to an increased risk of

accidents. Even modest noise levels are liable to interfere with rest and sleep and if noise is intermittent it is generally more aggravating and disturbing than if continuous. People vary in their tolerance to noise levels and patterns, but all are likely to be affected to a greater or lesser extent. The effect of noise on ground crews is very important. Noise induced fatigue or disturbed sleep mean lowered efficiency which has an adverse effect on maintenance standards and may lead to accidents.

(b) SPEECH INTELLIGIBILITY AND COMMUNICATION – Interference with intelligibility and speech communication is a very serious problem which can be brought about by higher levels of noise at certain frequencies. Although it may be associated with aggravation and disturbance it is a quite separate effect. This problem can prevent crew members communicating with each other, either directly or on an intercommunication system and can also interfere with voice communication between ground and aircraft. When sound pressure levels within cockpits and communication systems rise, the voice must be raised in order to communicate against the noisy background and if the interference becomes excessive, speech intelligibility becomes adversely affected or lost altogether. This is auditory masking or 'drowning out' by noise and only lasts whilst the noise is present. It represents the inability of the auditory system to separate the different tonal components and tends to be worse when the conflicting frequencies are similar. Apart from controlling noise sources, efforts must also be made to limit the entry of noise into the communication system. The position can be further improved by selecting the best possible characteristics for a communication system and by the use of special vocabularies so that the listener can anticipate the context of the message. Apart from engine and aerodynamic sources, noise can be generated by the cabin conditioning system, by electronic gear within the cockpit, certain types of oxygen regulators and of course the individual's breathing if the microphone is 'live' (as listed in paragraph 12). The degree

of interference will depend upon the relative frequencies and strengths of the voice or tone signal and the ambient noise level.

(c) HEARING DAMAGE – As noise levels increase, the threshold of risk of hearing damage will be reached. This denotes a level of noise which produces hearing loss, after different exposure times. Initially, the slight deafness which is caused recovers quite quickly during the period following noise exposure. Repeated exposures to high noise levels, however, can lead to permanent hearing damage. Although the detailed relationship between noise exposure and noise induced hearing loss cannot be stated quantitatively, long-term unprotected exposure to wide band noise levels over 90 dB can produce damage to the ear. There is evidence that single frequency noise is likely to be more damaging than wide band noise of the same energy and the ear is less tolerant to noises in the middle and high frequency bands. Noise levels much greater than 90 dB can evoke special responses even in a short time. For example, when the noise is very loud indeed (intensity over 120 dB) it can be felt in the ear and may cause pain; a level of 140 dB produces ear pain and the ear-drum might even be ruptured at levels around 160 dB. At these very high noise levels some people may also suffer from other effects, such as dizziness, nausea and vomiting, not directly associated with hearing and these may occur even if the external ear is protected.

PROTECTION FROM NOISE

17. There are a number of approaches to the problem of protecting noise exposed individuals and it is convenient to examine them under different headings:–

(a) GENERAL PRECAUTIONS ON THE GROUND – On the ground, efforts should be directed toward minimising the number of people who are exposed to high noise levels and reducing the amount of exposure for those who must work in noise exposed areas. For example, engine testing should, as far as possible, be carried out in a location remote from other working

areas so that the noise exposure is limited to the personnel directly involved in the tests. Natural screening or external noise baffles will help to reduce the size of the affected area. The general level of noise on an airfield is a feature of the layout and is affected by the sites at which ground running is necessary, the direction of the runways in relation to the working and living areas and any screening afforded by buildings and trees. Aircrew should remember these points when operating from forward tactical air-strips since they may be actively involved in planning the detailed layout. On permanent bases, the noise gaining access to buildings from external sources can be reduced by suitable insulation and by double-glazing the windows.

(b) PERSONAL PROTECTION ON THE GROUND – People who are exposed to high noise levels must be equipped with some form of ear protection and supervisors should ensure that these are used routinely and conscientiously. Ear protectors are of two general types: those which are inserted into the ear canal (ear-plugs) and larger and more efficient types which are worn over the ears (headsets, ear-defenders (ear-muffs) or noise excluding helmets). A combination of ear-plugs and ear-defenders gives more protection than either alone, but the total protection is not as great as the sum of that afforded by each device on its own. All these forms of protection tend to be more effective in the high frequency band. Ear-plugs must be kept clean and correctly fitted; some people find them uncomfortable and this may lead to their failing to use them routinely. In addition to their greater efficiency, especially at lower frequencies, external ear defenders have the added advantage that supervisors can readily see if ear protection is being used by noise exposed personnel. The wearers of ear protectors must develop an increased awareness of potential hazard when moving around an area where aircraft are manoeuvring, since they will no longer have the noise cues to which they have been accustomed. Special spun glass wool fibre (glass down) can be used to plug the ear canal and is useful, if

carefully inserted. It is more effective than cotton wool and is a help to people who find plastic ear plugs intolerable. Glass wool is particularly useful for passengers in noisy troop carrying aircraft (see paragraph 17c). The hazard of noise from gun-fire should be remembered and personnel must be adequately protected during target practice; this is particularly important when using high velocity rifles.

(c) IN-FLIGHT SITUATION – During flight, aircrews are protected from high ambient noise levels in the cabin by wearing well-designed helmet assemblies. 'Where air can get in, noise can get in' is an old adage and a reminder to ensure that headgear is well-fitted and kept in first-class condition. Passengers may also be exposed to unacceptably high noise levels when they are carried in military aircraft which are not primarily designed for that role. Apart from the question of discomfort or long term damage to hearing, these troops may be required to 'go into action' the moment they step from the aircraft. Thus it is important to reduce noise-induced fatigue and to ensure that their hearing is not so impaired, even temporarily, that they are unable to hear instructions. While ear defenders are ideal for this purpose, glass down correctly inserted in the ear canal will provide reasonable protection on such flights. In some helicopters there may be a larger element of low frequency noise coming from the main rotors and gearing so that ear defenders or helmets are more appropriate.

(d) HEARING CONSERVATION PROGRAMME – Finally, a 'hearing conservation programme' has a very important role to play. This is not only concerned with the problems of noise exposure and its effective control but also ensures that the hearing of all persons exposed to high noise levels is checked regularly. By so doing any noise-induced deafness likely to lead to permanent hearing loss if exposure continued, is detected at an early stage. The effectiveness of such a programme is dependent upon strict adherence to the regulations which are clearly laid down for the protection of hearing, both in the short and long term.

VIBRATIONS

18. Vibration denotes any fluctuating force which is 'felt' by a person rather than one which is 'heard' and is usually structure-borne but not always so. It has already been pointed out that certain 'noises' can affect individuals by making them dizzy or sick without having direct pressure effects on the organ of hearing itself. Excessive vibration, like noise, also reduces a person's efficiency by causing discomfort, irritation and fatigue. In general, however, the effects of vibration are limited to the occupants of the aircraft.

19. The principles underlying the control of vibration are associated mainly with the basic design of the aircraft and its component equipment. Various aircraft characteristics such as fuselage length and wing loading are, for example, very critical to the aircraft's vibration characteristics in the high-speed low-level role. Aircraft designers not only aim to minimise vibrations but also to ensure that residual vibrations are of such an amplitude and frequency that they do not cause serious interference with the comfort and efficiency of the aircraft occupants.

20. When the body is exposed to vibration, both the frequency and amplitude are significant and the effects upon the human body vary accordingly. The most important frequency range from the point of view of causing adverse effects on the body lies between 1 to 40 Hz (Hertz = cycles per second). Although the response to vibrations of the body as a whole is specific at 4–5 Hz, different parts of the human body start to oscillate at different frequencies outside that narrow range. This causes discomfort, fatigue and depending upon the amplitude of the particular oscillating force field, also makes it very difficult to keep the various parts of the body steady. It may also be difficult to read aircraft instruments, thereby interfering with crew duty and possibly leading to accidents. For example, the natural frequency of the head is around 17–25 Hz and the hand and forearm in the region of 40 Hz, thus these parts of the body resonate at these frequencies.

CONCLUSIONS

21. Noise and vibration constitute unwelcome features in modern high performance aircraft. Designers are not always successful in avoiding these problems and aircrews should be familiar with protective devices available to them and make full use of them. A hearing conservation programme plays an essential role in preventing deafness in people whose work involves exposure to noisy environments and every possible step should be taken to ensure that it is pursued.

- **NOISE AND VIBRATION CAUSE FATIGUE AND INEFFICIENCY AND MAY PRODUCE ACCIDENTS.**
- **PROTECTION FROM NOISE MAKES SENSE AND SAFEGUARDS HEARING.**
- **CONSIDER THE LONG TERM EFFECTS OF NOISE BEFORE IT IS TOO LATE.**
- **THE USE OF EAR DEFENDERS ON THE GROUND CALLS FOR CAUTION IN MOVEMENT AREAS.**
- **ENSURE THAT A HEARING CONSERVATION PROGRAMME IS FOLLOWED CONSCIENTIOUSLY.**

CHAPTER 14

VISION

INTRODUCTION

1. It is very important for all crew members to be aware of the various factors associated with effective vision. Whatever the aircraft role, the eyes play an essential part in the performance of a successful flight mission. In this chapter both visual detection and the problems associated with the interpretation of visual signals under difficult circumstances, will be considered.

ANATOMY AND PHYSIOLOGY OF THE EYE

2. The main anatomical features of the eye are shown diagrammatically in Figure 19. The tough white non-elastic outer coat of the eyeball is known as the *SCLERA*. At the front of the eyeball the sclera is replaced by the transparent *CORNEA* through which light enters the eye; the cornea is protected by a thin layer of tissue known as the *CONJUNCTIVA*. Since the cornea has a curved surface, the light which enters is refracted, causing the rays to begin converging. These light rays then pass through the *PUPIL* which is a hole in the centre of the *IRIS* and the amount of light which can enter the eye is controlled by its size. Just behind the pupil lies the crystalline *LENS* which continues the refraction of light thereby contributing to the production of an observed object on the *RETINA* at the back of the eye. An object is brought into sharp focus on the retina by an alteration in the curvature of the front surface of the lens. For example, when viewing distant objects, the lens is flattened by the outward pull of its suspensory ligaments which are attached to the *CILIARY BODY*. In the compartments of the eye, lying both in front of and behind the lens, there is fluid which also helps to refract (bend) the light as it passes towards the retina. The retina contains two types of cells which are sensitive to light and because of their shape, they are known as rods and cones. The cones are sensitive only to bright light, for example daylight or twilight,

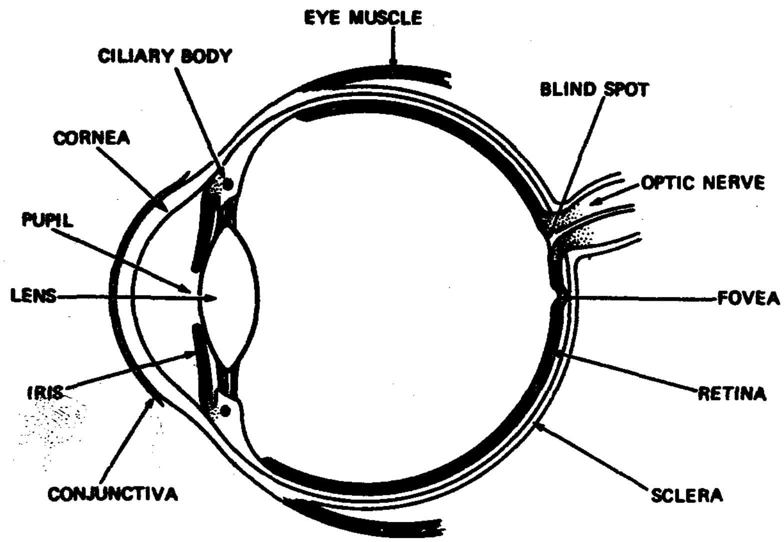


Fig.19 Structure of the Eye

whereas the rods respond also to very dim light. Although the image which is thrown on the retina is inverted it is perceived by the brain as being the right way up. The nerve impulses which are generated by the image falling on the rods and cones leave the eye along the *OPTIC NERVE.* The spot at which they leave the eye has therefore no light sensitive retinal cells and is known as the *BLIND SPOT.* The presence of a so-called 'blind spot' in each eye is not obvious because of the overlap effect of the field of view of the two eyes and also because that area is not in the direct line of sight, (see paragraph 12). When one is looking directly at an object, its image is thrown onto the retina at the fixation point, or *FOVEA*, which is the area with the greatest concentration of cones, (see Fig.19).

GENERAL CONCEPTS OF VISION

3. On the ground, a person may be able to get away with reduced or impaired vision but in the air such a situation is

nearly always dangerous. There are many factors which can reduce the normal efficiency of the eyes, such as hypoxia, G forces, toxic substances of various kinds, alcohol, tobacco and certain drugs. This is generally due to the fact that these factors have an adverse effect on the circulation and in particular on its ability to carry essential supplies of oxygen to the eyes. The main effects of these toxic substances and physiological disturbances are on the brain, however, which is responsible for perception. Visual disturbances may also be caused by a direct poisoning effect on the eye tissues, particularly the nerve cells. Fatigue also can have an adverse effect on vision; just as the whole body will feel listless so the eyes do not act as quickly and as efficiently as they should.

4. Diet is also an important factor, not only because of its effect on general health, including vision, but more specifically because certain vitamins are essential to the performance of the visual mechanism. For example, vitamins A and C are important for ensuring good vision and vitamin A is particularly essential to good night vision. Vitamin A is found in many foods, particularly in ox and calf liver and dairy produce; green vegetables and carrots contain 'carotene' which the body readily transforms into vitamin A. It should be noted, however, that if the body already has enough vitamin A, as in a well balanced diet, night vision cannot be improved by taking additional vitamin A. Vitamin C is also found in green vegetables, as well as in fresh fruit and certain fruit cordials; there is only a small amount in potatoes, if not overcooked, but this can be a useful source because of the quantity eaten.

DAY VISION

5. The cones, which can function in light levels ranging from bright sunlight through to moonlight, are more concentrated towards the centre of the retina, in the fovea. This means that in daylight the sharpest vision is along the line of sight and becomes poorer towards the outside of the field of vision, (see Fig.21).

6. The ability to see a distant object clearly in daylight depends, therefore, on getting it in the direct line of sight

and keeping it there for a sufficient length of time for the image to be 'recorded' in the brain, (see paragraphs 20 and 21). The other factors which are important to the range of visual pick-up are related to the characteristics of the target and atmospheric visibility, as follows:–

(a) Size (and range) of target.
(b) Reflected light from the target.
(c) Illumination of the target.
(d) Haze or fog.
(e) Contrast and camouflage.
(f) Speed of closing.
(g) Type of approach.
(h) Ancillary factors such as condensation trails, reflection of sunlight on the windscreen etc.

7. Many of these physical variables are self-explanatory but there are certain specific problems which will now be given special mention because of the significant effect they have on pick-up ranges.

REVERSED LIGHT DISTRIBUTION AT HIGH ALTITUDE

8. The brightness of the sky is caused by a scattering of light by atmospheric particles and is proportional to the atmospheric pressure, so that it diminishes as altitude increases. There is also likely to be a well-marked and bright cloud floor below an aircraft flying at high altitude. The net result of these two factors is that there is usually a great deal of light coming from below the eye level and very little from above. This creates a reversal of the usual light distribution in the field of vision as experienced on the ground. The contours of the human face are not designed to protect the eye from strong light coming from below. Light can therefore flood unhindered into the eyes giving rise to a sensation of glare mainly due to the light being scattered within the eyeball, resulting in haziness of vision. This reversal of the normal light distribution also tends to make the lower part of the cockpit dark, due to the shielding effect of the cockpit walls. The two effects, namely the haziness of vision and darkening of the aircraft instruments, together make it difficult to see clearly within the cockpit.

It is useful to protect the eyes from this bright light coming from below, but in severe cases the most satisfactory solution is to illuminate the instrument panel with a strong white light.

GLARE

9. There are two other types of glare worthy of mention. The first is caused by light falling uniformly on the retinal image and is usually associated with atmospheric haze or dirty aircraft windows. This can be reduced therefore by ensuring that transparencies are always kept as clean as possible. Another source of glare is due to looking directly at the sun, which momentarily reduces the overall sensitivity of the retina. This situation is difficult to deal with since it may be necessary to look at or near the sun whilst searching, and a filter which is sufficiently dense to reduce the discomfort will also reduce the effectiveness of visual search in other areas.

BRIGHTNESS CONTRAST

10. The maximum range at which an object can be seen depends not only upon its size but also on the contrast between it and the background, (see paragraph 6). Maximum brightness contrast will enable objects to be picked up at far greater distances than would otherwise be the case. An object of a given size can be seen even further away than the size would suggest, even at maximum contrast, if there is light emanating from the object. This is due to the fact that it is detectable by the light and not by a clear view of the object itself. This is significant in the choice of aircraft finishes since the 'glinting' of sunlight from bright reflecting surfaces will permit pick-up at extreme ranges.

COLOUR CONTRAST

11. Colour contrast between an object and its background has a marked effect on visual pick-up range. Two objects of the same brightness can be differentiated by colour contrast. These factors have a significant effect on the choice of colours used on aviation equipment and aids. It is

in order to provide a good colour contrast against the background of the sea that dinghies are painted a particular yellow colour, thereby making them easier to locate. This principle can be adapted for all ground markers according to the type of area in which they are likely to be used. Similarly areas of green vegetation stand out very well in desert areas. If on the other hand detection is undesirable, efforts are directed towards a reduction in colour contrast and the art of 'camouflage' can be extremely effective. Apart from the choice of light colours in this instance, dull finishes are also used in order to prevent glint.

SCANNING

12. The question of scanning an area in daylight has already been referred to in paragraphs 5 and 6. Maximum pick-up range lies directly along the line of sight, so the target area must be covered slowly and thoroughly. It is useful to 'divide' the search area into sections and cover each of them by means of a set pattern of head and eye movements, bearing in mind that the whole area must be covered by the 'cones' of central vision. When a target is eventually picked-up, detailed identification is most effective when the object is looked at directly. This is not so at night and this difference is discussed in paragraph 14. There are also special problems associated with searching a completely empty visual field and these will be dealt with in paragraph 23.

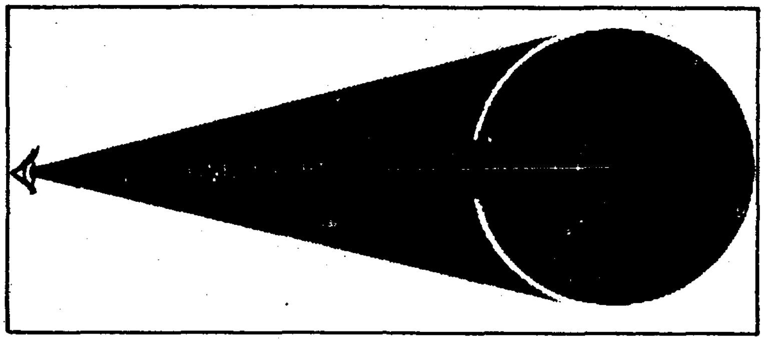
NIGHT VISION

13. The rods, which are the retinal cells more responsive to light of low intensity, begin to be effective about 3° off the fixation point and they are mostly packed together in a circle of radius between 10° and 15° from the centre or fixation point. That is the area of the retina which is most sensitive in conditions of low illumination and best suited, therefore, to observing objects at night. The fixation point itself, on the other hand, is more or less 'blind' under these conditions. For example, a faint star at night may disappear if looked at directly and reappear when the observer looks to one side of it.

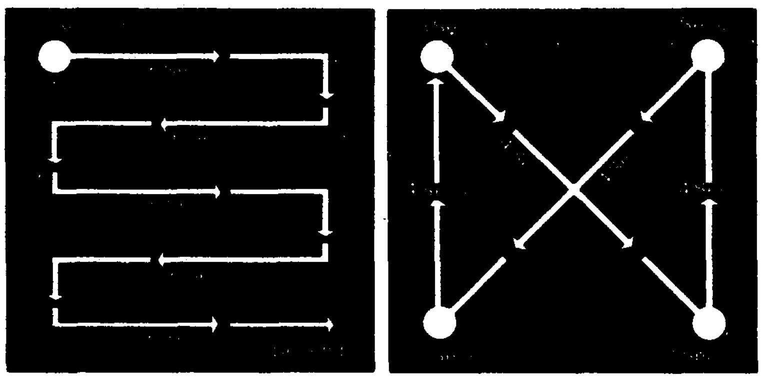
14. Thus, this feature of the retina means that in conditions of low illumination the best picture is obtained by looking 10° to 15° to one side of an object, (see Fig.20a). This influences the technique for carrying out a night search, examples of which are given in Fig.20b. By means of a slow regular scanning movement the eyes will not only cover the whole search area but objects will be picked up when they impinge upon the most sensitive area of the retina lying off-centre from the fixation point. Although both day and night searches employ scanning movements, at night it is essential *not to look directly at a faintly visible object when trying to* confirm its presence.

15. It is possible to pick-up faintly visible objects at night because of a retinal pigment called visual purple. This substance is bleached by light and reforms in darkness. After exposure to bright light it takes about 30 minutes for maximum visual sensitivity to be regained when the light has been removed. The eye is then said to be 'dark adapted'. On the other hand, it only takes a second for dark adaptation to be lost if the eyes are exposed to bright light. Provided that red light is not too bright it does not destroy 'dark adaptation' and it is for this reason that it has been used in aircraft cockpits. If dark adaptation is needed immediately after take-off, red goggles can be worn in a dimly lit crew room in order to promote dark adaptation *prior to the beginning of a mission.* The eyes work independently in this context and if it becomes necessary to look at a bright light, one eye only should be used and the other eye will retain its dark adaptation. This will only work if the light source is not too bright otherwise there may be a disturbing 'after-image' in the eye which was exposed to the bright light, even after the light source has been removed. This means that the image of the glaring object would be seen for some time.

16. Hypoxia has a detrimental effect on night vision. At 1,200 m (4,000 ft), the loss in night vision could be as much as 5% gradually increasing to some 40% at 5,000 m (16,000 ft). For this reason oxygen is usually used from ground level at night.



(a) A diagrammatic representation of the relatively 'blind' area of central vision in conditions of low illumination emphasising the need to look 'off-centre' in these circumstances.



(b) Suggested methods of scanning the 'night sky'; the essential points being to cover the area thoroughly and keep the eyes moving slowly and steadily.

Fig.20 Night Vision

17. Because of the special problems associated with scanning at night, simple night vision training such as practising scanning techniques, can be of great practical value. In the aircraft cabin, low intensity red light should be used wherever possible because this will have the minimum detrimental effect on night visual acuity.

18. These various aspects of night vision and the ways of making optimal use of the eyes can be very important, particularly in the operational situation; the following 'check-list' will help to summarise all the various points which are important if a high standard of night visual acuity is to be attained:

(a) Ensure an adequate intake of vitamin A.

(b) Avoid fatigue, sleeplessness and excesses of tobacco or alcohol.

(c) Carry out ground training practice in night scanning techniques.

(d) 'Dark adapt' by wearing 'red goggles' (for at least 30 minutes before take-off if full night vision is required).

(e) Ensure that all aircraft transparencies (and spectacles) are scrupulously clean.

(f) Avoid headlights on the airfield and high intensity light in the cabin.

(g) If white light (e.g. a torch) is necessary use one eye only.

(h) Use oxygen from ground level.

(j) Make maximum use of peripheral vision in search pattern.

(k) Observe target 10° to 15° off line of sight.

(l) Use contrast to your advantage, (for example, in formation it may be easier to see lead aircraft against sky rather than ground background, depending on colour).

VISUAL PERCEPTION IN HIGH PERFORMANCE AIRCRAFT

19. There are a number of problems related to visual perception in high performance aircraft which are sufficiently important to merit special mention and these will now be considered.

EFFECTS OF DISTANCE AND SPEED

20. As aircraft speeds increase it is no longer valid to think in terms of an instantaneous visual picture. The time that it takes to perceive an object, (i.e. to be aware of its presence), 'perception time' as it is called, becomes significant and is made up of a number of factors:

(a) The time for information to pass from the eye to the brain, indicating that an object has been picked up on the edge of the visual field;

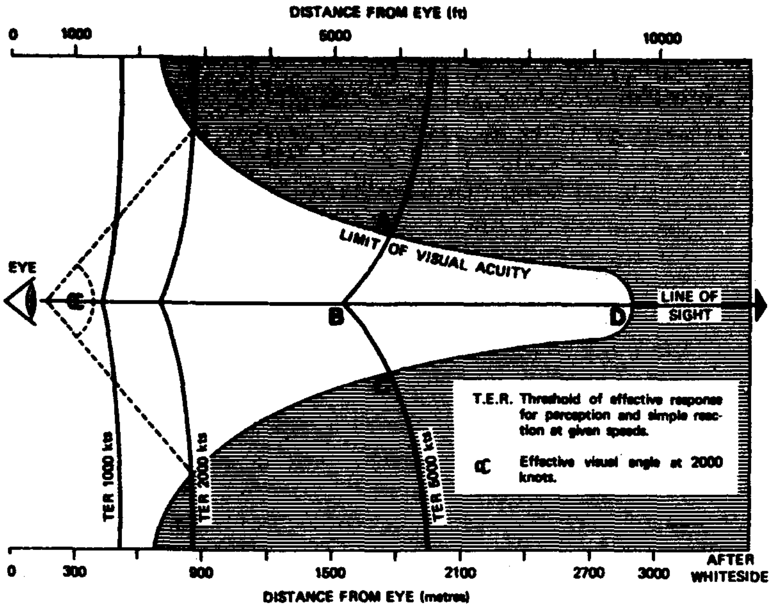
(b) The time for the eye to turn toward and focus on the unknown object;

(c) The time involved in recognising the object.

21. The total delay if of the order of 1.1 seconds and indeed some 2 seconds or longer may be necessary to recognise and consciously assess a complex situation. At high speed, time delays of this order represent a considerable closing distance over which the eye is effectively unable to perceive an object. When eventually it is perceived, the object may already have been overtaken (see Fig.21). An object which suddenly appears in that 'blind' area does not elicit any useful response from the observer since his aircraft would have passed the object before he perceived it and was able to react to it. The shape of that area is also affected by the cone-shaped limit of visual acuity and assumes normal vision. The data used to construct Fig.21 do not take into consideration the question of aircraft response to control movement. This further delay must be added if there is any question of taking avoiding action.

VISUAL ILLUSIONS AND DISTORTIONS

22. There are occasions when the visual picture can be misleading and it is important to be aware of these circumstances. Three types of visual illusion namely, 'autokinetic', 'oculogyral' and 'oculogravic' have already been dealt with in Chapter 11. Apart from these illusions, the visual picture can be distorted physically by looking through transparencies at acute angles and by dirty or wet windows. It is very important to ensure that all visual equipment is maintained to a high standard. Polarizing spectacles may



Note: (1) the restriction of visual range in the periphery of the visual field;

(2) the effect of speed on the size of the area between the eye and the 'threshold of effective response';

(3) at 5,000 knots closing speed, objects can only evoke useful responses in the area ABCD.

Fig.21 Effective Vision at High Speed

cause problems because they may show up all the strain patterns in plate-glass and plexiglass, particularly against a high altitude sky.

PROBLEM OF SCANNING IN AN EMPTY VISUAL FIELD

23. Visual search at high altitude usually entails scanning an area in which there is nothing on which the eye can focus. An empty visual field need not be devoid of light and can have any degree of brightness. It can be clear blue sky,

total darkness, a 'grey' overcast sky, haze or fog. In such situations where there is 'nothing to see', there is equally no stimulus to cause the eye to focus at infinity. The focus of the eye tends to 'wander' between far and near which explains why, during such a search, the observer may suddenly find that his eyes have focused on the windscreen. A conscious effort to look into the far distance does not cause the lens muscles to relax and the eyes to focus at infinity. On the contrary, this is likely to have the opposite effect and bring the point of focus even nearer than the normal resting level. The only sure way of focusing beyond the resting level is to look at an object at least 6 m (20 ft) away, every three or four seconds. By 'locking-on' to an object such as a cloud edge or part of the aircraft the eyes will then be kept at distance focus. It is difficult to judge distance, relative speed and the size of an object when it is seen in an empty visual field and objects seem much further away than they really are.

FLASH BLINDNESS

24. Flash blindness is a temporary dazzle condition caused by exposure to high intensity light, such as atomic flash. Its duration may extend from a few seconds up to several minutes depending upon what one is trying to see. There are many possible methods of protecting the eyes from this effect: including the use of cockpit shades, blinds, or by covering one eye with an eye-patch. The suitability of any of these methods depends on the aircraft type and the particular operational situation. The simple procedure of covering one eye during the time when an atomic flash is expected keeps the eye that has been covered in reserve for use when the other has been temporarily blinded. There is also the real eye hazard of retinal burn which can be permanent and which may be sustained by anyone looking directly at a nuclear fireball.

CONCLUSION

25. This subject has been dealt with in considerable de because of the importance of vision to the aviator. T

most modern complex weapon systems are ultimately dependent upon an efficient visual contribution from the aircrew concerned.

- **IN DAYLIGHT THE SHARPEST VISION IS ALONG THE LINE OF SIGHT.**
- **AT NIGHT OXYGEN SHOULD BE USED FROM GROUND LEVEL.**
- **SAFEGUARD DARK ADAPTATION AT NIGHT AND USE PERIPHERAL VISION.**
- **KEEP ALL TRANSPARENCIES CLEAN AND FREE OF SCRATCHES.**
- **BEWARE THE HAZARD OF LOOKING DIRECTLY AT NUCLEAR FIREBALL.**

CHAPTER 15

TOXIC SUBSTANCES AND COUNTER-MEASURES

INTRODUCTION

1. The list of toxic substances which can occur in aviation is now very long and will continue to grow as new materials are used in the construction, operation and maintenance of aircraft. Substances are said to be toxic when, under certain circumstances and in sufficient concentration, they become harmful to the human body. In some cases, raised temperature and lowered atmospheric pressure are significant factors in producing or aggravating toxic effects.

2. Since the aircrew task calls for a high degree of skill and efficiency, the effects of toxic substances need not reach levels which in themselves are considered dangerous to the body before they are hazardous to an aviator; even mild toxic effects can lower an individual's performance sufficiently to produce an aircraft accident or an abortive mission.

3. The main potentially dangerous substances will be discussed in separate groups, since it is not possible, and in most cases not necessary in a document of this kind, to deal with each and every compound individually.

FUELS AND PROPELLANTS

4. There are now a great many types of fuel in use and aircrew can be exposed to them in either liquid or vapour form, both on the ground and in the air. Ground personnel may also be exposed to the hazards of these substances in the pre-flight situation and apart from causing any personal hazard, this can diminish ground crew efficiency to a point where the aircraft and its crew are also endangered.

(a) PETROL (AVGAS)

(1) The principal constituents of AVGAS are aliphatic and aromatic hydrocarbons; (i.e. derived from benzene and natural petroleum); there are also

certain additives such as tetraethyl lead, aniline and toluene. Petrol vapour can produce symptoms in non-inflammable concentrations; its effects on the central nervous system cause a loss of sensation and reduction in consciousness. Its anaesthetic effect on the lining of the nose dulls the sense of smell; this is a dangerous feature since it diminishes an individual's awareness of continued exposure. AVGAS also irritates the eyes and throat and in some 10-20% of cases, also the bowel. The usual toxic symptoms are: headache, nausea, excitement, blurring of vision, mental confusion and inco-ordination. If the concentration is high enough, unconsciousness and death can intervene. In practice, the detection of a strong smell of fuel vapour should be taken as a warning to seek improved ventilation. AVGAS has a local irritant effect on the skin and repeated contact can produce a skin sensitivity.

(2) The greatest hazard of AVGAS intoxication is associated with cleaning the interior of petrol storage tanks. This is aggravated by a dulling of the sense of smell to the extent that the cleaners are unaware of a rise in concentration of fumes in the air. The additive, tetra-ethyl lead, is a volatile substance which is absorbed through the lungs. It affects the central nervous system, producing: general weakness, muscular inco-ordination and mental disturbances.

(b) GAS TURBINE FUELS

(1) A gas-turbine engine can operate with a wide variety of fuels but for practical reasons only petroleum hydrocarbons are commonly used. AVTUR is a kerosene-type of fuel, whereas AVTAG is a wide-cut gasoline.

(2) Kerosenes affect the central nervous system after entering the body through the lungs.

(3) The harmful effects of these fuels and the problems of handling them are not materially different from those which have been described for AVGAS.

(4) AVPIN or isopropyl nitrate is a highly inflammable liquid used for starting turbine engines. Its main hazard lies in its combustion products which cause marked irritation of the lungs.

(c) MISSILE PROPELLANTS AND OXIDISING AGENTS

(1) The constituents of rocket fuels are usually toxic. Aniline is used in some liquid propellant mixtures and although it has a pleasant non-irritant odour, is dangerous. It is absorbed through the lungs and skin and causes shortage of breath, weakness, dizziness, diarrhoea, muscular incoordination and mental disturbances.

(2) Liquid oxygen, fuming nitric acid and hydrogen peroxide are used as oxidisers in various liquid propellants. Oxygen is liquid at a temperature of $-183°C$ and can cause frostbite and skin burns. Vapour trapped in clothing can cause explosive fires and organic materials, particularly oils, may detonate readily after contact with liquid oxygen. Nitric acid and hydrogen peroxide cause severe burning on contact with the skin. Their vapours cause marked irritation of the eyes and respiratory tract.

(3) The principles underlying the safe handling of propellant fuels and oxidisers are based on an understanding of the hazard of the particular material and should an accident occur, rapid and adequate self-aid and first-aid to limit the danger.

PRODUCTS OF COMBUSTION

5. The products of combustion or heat are the commonest source of toxic hazard in aviation and the type of product which is evolved depends upon the nature of the particular material which has been burned or heated. The potential toxic effects of exposure to fire products in aircraft are therefore very complex. In fires it is common for the oxidation of the various materials involved to be incomplete, thus producing principally carbon monoxide, aldehydes, various other intermediate break-down products, (depending

upon the nature of the particular material involved) plus some carbon dioxide and water vapour. The aldehydes are irritant and soon make their presence felt, carbon monoxide (CO) on the other hand is a particularly dangerous substance because of the insidious nature of the toxic symptoms and the fact that it is practically odourless.

6. As far as engine exhaust gases are concerned, high concentrations of CO are associated with piston engines but not with jet engine efflux; the latter consists mainly of air, together with some 5% water vapour and CO_2, since the combustion of the fuel is so efficient that it is virtually complete. In piston engined aircraft, carbon monoxide contamination of the cockpit is commonly associated with defective sealing of the bulkhead or a defective cabin heating system which uses exhaust gases in a heat exchanger.

7. The fact that carbon monoxide is a major product of combustion and has such insidious qualities, means that it requires description in some detail. It is interesting to note that it is also considered to be potentially the most troublesome contaminant in sealed cabins during extended space flight because it can have seriously deleterious effects on crew performance, even in very low concentrations.

CARBON MONOXIDE (CO)

8. When carbon monoxide is inhaled, it passes across the alveolar membrane of the lung into the blood stream where it enters the red blood cells to combine with the haemoglobin and it has about 250 times as great an affinity for haemoglobin as has oxygen. Therefore with a normal alveolar oxygen tension of 103mm Hg a carbon monoxide tension of, say, 0.4mm Hg in the alveoli would cause a progressive change from oxyhaemoglobin to carboxyhaemoglobin in the arterial blood. This reduces the amount of oxygen which is carried to the tissue cells and decreases altitude tolerance. Carboxyhaemoglobin also reduces the ability of the circulating blood to release its oxygen to the tissues; this becomes critical during exercise and hypoxia.

9. Under resting conditions, at sea level, there are usually no symptoms associated with carbon monoxide 'poisoning' until more than 10% of the circulating haemoglobin has been saturated with carbon monoxide (this assumes a normal blood haemoglobin level). With increasing blood saturation, however, symptoms begin to appear, as shown in Table 5. The hazard of carbon monoxide to the aviator increases sharply as altitude increases, because the presence of carboxyhaemoglobin in the circulating blood accentuates the degree of hypoxia which might otherwise be present. For example, a concentration of 0.01% CO in the air, which would be safe on the ground, reduces the oxygenation of the arterial blood by 10.5% and when this is superimposed on the reduced arterial oxygen saturation at say 3 000 m (10,000 ft), it results in a dangerous state of hypoxia. At ground level, a concentration of twice that amount of CO in the air would only cause a mild headache, even after 2-3 hours exposure. It is important to remember also that heavy smokers already have an elevated base line carbon monoxide saturation of 6-8% and moderate smokers about half that amount.

10. The immediate treatment of carbon monoxide poisoning is the restoration of normal breathing; the patient needs as much fresh air as possible and oxygen should be administered if it is available. If respiration has ceased, artificial respiration must be carried out immediately (see Chapter 18). In the investigation of a suspected case of carbon monoxide poisoning, a blood sample should be taken as soon as possible for laboratory investigations. For this reason, as well as for expert guidance in the treatment of the condition, it is important that the individual is seen by a medical officer as soon as possible.

FIRE EXTINGUISHING AGENTS

11. There is no ideal fire extinguishing agent for use in aircraft because of the difficulty of finding an extinguisher which can deal with all types of fire, irrespective of the nature of the material involved. The agent must also be non-toxic both in its normal state and when it is decomposed in

TABLE 5

SYMPTOMS OF CARBON MONOXIDE POISONING

% of Circulating Hb Saturated by CO	SYMPTOMS (resting state, at ground level)
0–10	None noticeable.
10–20	Tightness across forehead and slight headache.
20–30	Headache and throbbing of the temples; breathlessness on exertion and perhaps nausea.
30–40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, collapse.
OVER 40	Increasing likelihood of collapse, increasing pulse rate, irregular breathing, coma, convulsions, respiratory failure.

use; many otherwise efficient fire extinguishing substances are particularly dangerous when exposed to the heat of a fire, because of their breakdown products. Finally, a fire extinguishing agent has to be effective in as small a bulk as possible.

(a) METHYL BROMIDE is a most effective fire extinguishing agent, but it is highly toxic. Acute poisoning by this substance may have a delayed onset of up to 6 hours in milder cases; but the onset of sleepiness, double vision, headaches, sickness, paralysis and convulsions may lead to a fatality. Poisoning due to chronic exposure to this substance causes headache,

lethargy and some brain damage. Methyl bromide is no longer used where there is any danger of its gaining access to the aircraft cabin. Two other similar substances are used as fire extinguishing agents, namely, carbon tetrachloride and chlorobromomethane.

(b) CARBON TETRACHLORIDE degrades to phosgene gas when it is heated and this is an intensely toxic gas which can produce respiratory collapse at very low concentrations. CHLOROBROMOMETHANE is less toxic in its normal state than carbon tetrachloride, but is also toxic when it is heated, due to the production of phosgene.

(c) MONOBROMOTRIFLUOROMETHANE is a newer liquid fire extinguisher which is virtually non-toxic in its normal state but when burned it produces bromine and fluorine.

(d) CARBON DIOXIDE in its gaseous form has been used extensively as a fire extinguishing agent, but it does not deal very effectively with combustible material such as paper and cloth. As a solid it is used as a refrigerant (dry ice). From the hazard point of view, it should not be used in enclosed spaces. Whenever a subject breathes a high CO_2 atmosphere, he suffers from symptoms which are due to lack of oxygen. At lower concentrations (say below 5%), these may consist of headache, lassitude, shortness of breath and perhaps dizziness. As the concentration increases, all the symptoms of hypoxia become more severe and at concentrations of 10% and more, unconsciousness supervenes, leading to death, unless the victim is removed to a normal atmosphere or given oxygen.

HYDRAULIC FLUIDS

12. At one time, hydraulic fluids had a castor oil base which contained a mixture of volatile compounds and were flammable, but most of them now have a mineral base and are not very volatile so their vapours possess a lower toxicity. The effects of these fluids on the human body depend upon the particular formula but, in general, any vapour which is produced is likely to cause mild irritation of the eyes and respiratory passages with some nausea and anaesthesia. Hydraulic fluids are usually under high pressure and a ruptured line can cause a fine spray of fluid which may be inhaled or ingested in droplet form.

LUBRICATING OILS

13. Oil leaking onto a hot surface produces aldehydes as break-down products and the smoke which is produced irritates the upper respiratory tract.

DE-ICING FLUIDS

14. These fluids usually consist of various mixtures of ethyl alcohol, methyl alcohol, propylene or ethylene glycol and water. These substances are not very toxic unless the concentration is particularly high. The usual cause of contamination in an aircraft cockpit is the fracture of a de-icing line permitting a fine spray to enter the cabin. This may produce irritation of the eyes and nose and also headache and nausea. The symptoms are not usually severe, but the irritation of the eyes can cause them to water and make it very difficult for the individual to see adequately.

REFRIGERANTS

15. Refrigerant gases such as FREON and ARCTON are in themselves usually safe, but decomposition by heat produces gases such as chlorine, fluorine and phosgene, which are dangerous. DRY ICE is also used (see paragraph 11 (d)).

PLASTICS

16. Many different types of plastic are used in the manufacture of aircraft fittings and as insulation for electrical wiring. Although most plastics are inert at normal temperatures, when heated or burned, their many and varied break-down products can be toxic, producing irritation of the lungs and damage to the central nervous system if the concentration is high enough.

INSECTICIDES, HERBICIDES AND OTHER AGRICULTURAL CHEMICALS

17. A wide variety of these chemicals is carried by air and aircrews or passengers may be accidentally exposed to them. These agents can gain access to the body through the skin, lungs or gastrointestinal tract and their actions vary according

to the dose and chemical composition. The symptoms can be very severe and dangerous, so that great care is required in handling these substances and accidental contamination calls for expert medical treatment as soon as possible.

LOX

18. Liquid oxygen (LOX) is commonly used to provide a light-weight, compact breathing system for aircraft. LOX can be contaminated fairly easily in the manufacturing process by whatever undesirable substance may be in the atmosphere at the time of manufacture. These contaminants are then concentrated during the manufacturing process and may 'freeze-out' in the LOX as solid particles and subsequently evaporate in the system and be breathed in high concentrations. Many substances can cause such contamination, some of which are toxic and others which may only give rise to characteristic smells; although not in themselves dangerous these may lead the user to believe that danger exists. High standards of manufacture are therefore necessary in the production of LOX to ensure that contamination is minimised. The other hazards of LOX, namely frost-bite and fire or explosion, have already been mentioned when dealing with oxidising agents.

OZONE

19. Ozone is a tri-atomic oxygen (O_3) and is formed by the shorter ultra-violet wavelengths being absorbed by oxygen. This subject has already been discussed in the chapter dealing with the physical characteristics of the atmosphere. Ozone is highly toxic when inhaled, even in small quantities.

ACTION IN THE EVENT OF COCKPIT CONTAMINATION

20. When the cockpit becomes contaminated with noxious substances, action must be taken to prevent inhalation of the contaminant; this action will vary with the particular oxygen system in use. The aim is to breathe 100% oxygen and take all action to prevent inboard leaks, including closing any air inlet fitted to the regulator and selecting emergency pressure, as appropriate. Action should also be taken to prevent

irritation of the eyes by wearing goggles or a vizor. Similarly, covering as much as possible of the skin surface prevents or minimises skin contamination.

21. Cockpit ventilation should be improved as far as possible, as long as this does not aggravate the situation. Aircrew should also bear in mind, however, the insidious nature of carbon monoxide poisoning and the fact that the gas is non-irritant; it may be associated with an unusual smell, from a heating duct for example and this should be taken as useful warning of possible danger.

CONCLUSION

22. Although there are many toxic hazards in the field of aviation, high standards of servicing and the adherence to the correct procedures can reduce these to a minimum. If contamination does occur, action should be taken so as to avoid inhaling these products and reduce the time of exposure. Individuals who have been exposed to any toxic hazard should be referred for expert medical attention as soon as possible.

- **NOT ALL TOXIC HAZARDS ARE IRRITANT AND THEREBY PROVIDE WARNING.**
- **BEWARE THE INSIDIOUS NATURE OF CARBON MONOXIDE POISONING.**
- **WHEN IN DOUBT SELECT 100% OXYGEN AND EXCLUDE CABIN AIR.**
- **KNOW THE SUBSTANCES YOU DEAL WITH AND APPROPRIATE FIRST-AID MEASURES.**
- **SEEK EXPERT MEDICAL HELP AS SOON AS POSSIBLE AFTER CONTAMINATION.**

CHAPTER 16

ESCAPE FROM AIRCRAFT IN FLIGHT

INTRODUCTION

1. The situations which lead to the abandonment of an aircraft in flight are many and varied. Having made the decision, aircrew should be able to escape with a reasonable chance of success, even in an extreme emergency. The increase in aircraft speed has made it necessary to provide an assisted escape system.

CONVENTIONAL ESCAPE FROM AIRCRAFT BY PARACHUTE

2. Since the early days of flying, parachutes have undergone considerable development both in terms of their configuration and the material of which they are made. Numerous different parachute assemblies are currently in service in the NATO Air Forces and it is not appropriate to discuss their technical details in an aeromedical handbook. This chapter is concerned with the human aspects of parachute escape techniques.

3. Conventional escape implies that an individual can 'bail out' without assistance from any mechanical device within the aircraft. It is therefore restricted to his own physical efforts, any aircraft manoeuvre which he might be able to perform, or the help of gravity. At speeds greater than 200 knots it is extremely difficult to escape from an aircraft unassisted, particularly if the situation is worsened by accelerations due to uncontrolled aircraft manoeuvres, such as a spin or spiral dive. At high indicated air speeds, the strong force of air across the top of the cockpit or hatchway makes it difficult for an occupant to escape and increases his chances of fouling some part of the fuselage or tail. In larger aircraft, the occupants are further handicapped by the difficulty of reaching the escape point particularly if their movements are hampered by the effects of G forces. Inflatable bags have been designed to push an individual out of his seat and start him on his way to the exit.

4. Having cleared the aircraft structure, the correct time for opening the parachute varies with the situation. At very low altitudes, the parachute should be opened as soon as possible; a time delay of the order of one second should be adequate. At very high altitudes on the other hand a delayed parachute opening is necessary for three reasons. Firstly to prevent exposure to high opening shock forces, (see Chapter 10), secondly, to avoid exposure to hypoxia and thirdly to reduce the time spent at low atmospheric temperatures.

5. Having safely deployed the parachute canopy at an acceptable altitude, the remaining consideration is to ensure a safe landing. It is often very difficult to judge height above the ground and it is important that the speed of impact is not increased by spilling air from the canopy at the time of landing, by attempting to control the parachute descent at that late stage. There is no reason why oscillation should not be controlled during the descent, as long as there is sufficient height in hand to complete these manoeuvres before landing.

6. Where possible, the landing attitude should be adopted by about 300 m (900 ft) above the ground, that is, well before impact. The feet and legs should be together, knees slightly bent, head well tucked in; and the arms, with the hands grasping the lift webs, should be at right-angles, with the elbows held well forward. It is important not to retract the legs prior to impact since this is likely to cause injuries to the pelvis and spine. It is probably best to look forward at an angle of about 45 degrees, not straight down, thereby reducing the temptation to retract the legs at the last minute when the ground is seen to be close. When the feet do touch the ground, the body should be allowed to collapse in the direction the parachute is moving, thus distributing the impact forces over a larger area of the body.

7. After landing, it is important to collapse the parachute or release it, as soon as possible, to avoid injury through being dragged. When descending into water the impact itself is usually of little concern but the possibility of being dragged with the head under the water and possibly drowned, particularly in strong winds, is very real. On entry into the water, when the life jacket should already be partly inflated,

the parachute canopy riser releases (or the parachute quick release box) should be undone as soon as possible and the parachute discarded. It is very valuable to be a swimmer and therefore 'at home' in the water, because these latter escape manoeuvres may have to be carried out whilst being dragged head-down under the surface.

ESCAPE FROM HIGH PERFORMANCE AIRCRAFT

8. The most common method of assisted escape from high performance aircraft is by means of an ejection seat. This provides a life-saving facility, but as indicated air speeds increase, the present open ejection seats do not give protection against the increasing problem of wind blast. Closed escape systems have already been developed, both in the form of an escape capsule and a jettisonable cabin, but not many of these are in routine service.

9. An ejection system should provide three main facilities:
   (a) Sufficient thrust to eject the occupant clear of the aircraft structure, and particularly the high vertical stabilizing fin, even when the aircraft is out of control.
   (b) The capability of providing an adequate trajectory, even during low-level ejection, to allow full deployment of the main parachute before landing.
   (c) The ability to meet these escape profile requirements within levels of acceleration which are tolerable to the body.

10. Downward ejection seats were developed so that the aircraft structure could be cleared at low values of ejection thrust, but these had the drawback of limiting the low-level capability of the seat when the aircraft was in the upright attitude near the ground. More recently, rocket (or rocket-assisted) seats have been developed which provide longer durations of thrust, thus improving upward ejection trajectories without exceeding the maximum peak accelerations which can be tolerated by the human frame.

11. There are many varieties of ejection seat in service with the NATO Air Forces. In principle they consist of a rigidly constructed seat which is ejected from the aircraft structure

by means of an explosive charge or series of charges, with or without rocket burn. The upward ejection seat was the first type to be developed, because it was capable of being fitted to existing airframes and the canopy opening provided a convenient exit area; this is still the most common type of ejection seat in service today. In considering assisted escape, only the main principles of a typical escape system will be described in so far as they affect the user during the various stages of an emergency. As stated in paragraph 1, it should be possible to escape from an aircraft even under the most adverse conditions. Regrettably there are many cases on record where the full capability of an ejection seat has been wasted by inefficient escape techniques. It is pointless to provide an ejection seat with a ground-level capability if drills and techniques are allowed to use up valuable time which represents the equivalent of a considerable amount of height. The salient features of the various phases of escape will now be reviewed, starting with certain all-important pre-ejection considerations. A realistic approach to ejection seat training will then be discussed in the light of these various points.

PRE-EJECTION CONSIDERATIONS

12. Prior to any ejection, a decision must be made and the timing of that decision could make the difference between a successful escape and a fatal outcome. Many aircrew have failed to survive aircraft emergencies occuring at altitudes which were sufficiently high to allow a successful escape because they either failed to eject, or left it too late. In single seat aircraft, this problem is concerned with the minimum effective safe height for ejection; in multi-seat aircraft there is the added problem of conveying the executive order to eject to other crew members, so that they can escape also.

(a) MINIMUM SAFE HEIGHT – The minimum safe height for ejection refers to the straight and level situation. Aircraft attitude has a pronounced effect, therefore, on the minimum safe height for ejection and it seems that this factor is often under-estimated. There are a number of possible explanations for this. It may

be due to the feeling that the aircraft can be brought under control at any moment and perhaps this is strengthened by the fear of killing people on the ground if the aircraft is abandoned. It may simply be a fatal under-estimation of the height required for safe ejection, in a given aircraft attitude; a situation which can be made worse by miscalculating the time it takes to carry out an ejection sequence. The question of ejection drills will be dealt with separately. Finally, it may be due to mis-reading the altimeter, particularly if the pilot is disorientated or his vision is disturbed for any reason. In summary, an ejection seat with a ground-level capability may have an effective minimum safe ejection height of the order of thousands of metres when escape is attempted in a high speed diving attitude.

(b) EMERGENCY DRILL IN MULTI-SEAT AIRCRAFT – A difficult situation can arise in multi-seat aircraft, because of the need to communicate with the other crew members urgently and effectively, so that all can escape successfully. Situations have arisen where crew members have failed to respond immediately to the executive order to abandon the aircraft. In certain new aircraft this has led to a form of interlinking between ejection seats; by so doing, one ejection seat can fire another automatically as it leaves the aircraft. In aircraft not equipped with this device the problem still remains however. It is essential for aircrew to be absolutely clear as to their actions when crew members fail to respond, or are unable to hear the order to eject in situations of extreme emergency. In cases of this kind, where disaster is imminent, the pilot may best serve his crew by ejecting forthwith, so that they may be left in no doubt as to the seriousness of the situation.

EJECTION DRILL

13. Since modern ejection seats are designed to permit escape under extreme conditions of flight, it is important that ejection drills are kept to the bare essentials. This does not refer to any emergency R/T call which may be made,

but simply to the actions which are necessary to make a safe escape from the aircraft. Ideally an individual should be able to eject, with a reasonable guarantee of successful uninjured escape, using the normal seated position he adopts for routine flight. In single seat or dual control training aircraft something approaching this state of affairs does exist, but the situation is less than ideal where the crew member has to undo his seat restraining harness, or move from his seat, to carry out his normal aircrew duty.

14. Different ejection seats have their own methods of initiating the firing mechanism. In some this is located on the arm rest of the seat; others are fired by extracting a face blind from a stowage located behind the head; yet another group of seats is fired by pulling a handle located between the legs, on the front of the seat pan. Some ejection seats are fitted with more than one method of initiating seat firing. Leg restraining gear has been incorporated in many ejection seats to ensure that the legs are drawn back automatically during ejection and held together on the front of the seat pan, with the knees a few inches apart, when clear of the aircraft. This provides leg clearance during ejection and prevents the legs from flailing after ejection. Thus no special drill is required with regard to the legs and indeed it is better to allow the restraining gear to withdraw the legs from the rudder pedals.

15. With the increased automation of ejection seats the ejection drill is kept to the very minimum and in most cases the seat occupant, apart from initiating the firing mechanism, has little if anything to do apart from checking that his body posture is good. There are still a few aircraft in service, however, in which the seat position may have to be adjusted; the canopy fired manually rather than automatically and the flying controls cut by some device. These situations are no longer common and aircrews will be acquainted with these matters during their training.

POSTURE DURING EJECTION

16. The posture of the body is probably the greatest single factor in determining whether or not the seat occupant is

injured during an ejection sequence. If the spinal column is correctly positioned and supported during ejection, it can safely tolerate the accelerations imposed upon it without damage.

17. When viewed from the side, the natural line of the spine is in the form of an S, the curvatures being produced by the shape of the vertebral bodies and their adjacent surfaces are separated by a disc-like pad which acts as a cushion. During bending or twisting these pads alter their shape and the edges of the vertebrae come closer together. The spine is strongest and best able to accept loads when it is in its position of normal alignment, since the surfaces of the vertebrae are in maximum apposition with each other. In this erect position, the spinal column can withstand acceleration forces up to 25 G, peak accelerations, reached at not more than 300 G per second, whereas when it is flexed or twisted this figure can drop to 9–14 G at considerably lower rates of rise.

18. Spinal injuries during ejection most commonly occurred in the small of the back (the 12th thoracic and 1st and 2nd lumbar vertebrae being particularly susceptible). Recently, however, the pattern has changed in some aircraft and injuries have been occurring at higher levels (8th and 9th thoracic). This seems to be due to altered posture either because the included angle between the line of thrust and the spine has been changed or the support in the small of the back is incorrect. This emphasises further the overriding importance of body posture in the matter of ejection. The damage is not usually very severe fortunately and recovery should be complete after a period of bed rest.

19. The optimal spinal posture has been described as 'sitting to attention' and the significant points are as follows:

(a) The buttocks should be positioned as far back as possible on the seat and kept in that position. The small of the back should be supported by adjusting the back pad which is supplied with certain seats. If a back pad is allowed to slip down behind the buttocks this will not only deprive the spine of support but also push the buttocks forward; these factors together cause

a dangerous flattening of the normal lumbar concavity at the bottom of the spine.

(b) The safety harness should be correctly adjusted and comfortably tight; if it is overtight it may accentuate the thoracic convexity of the spine.

(c) During the ejection procedure, the head should be braced firmly against the head rest. It is important to maintain this attitude as long as possible and in particular not to relax during the time interval which may be built in for automatic canopy jettisoning. If the body is allowed to relax during this time, the spine may suffer from the loss of 'splinting' which is provided by the tension of the trunk muscles.

20. The seat pack, through which the ejection acceleration is transmitted, the support produced by the back pad and the effectiveness of the restraining harness, are all of the utmost significance to successful seat ejection without injury. The user can only adopt and maintain a posture as good as the equipment will allow. A variety of personal survival packs are in use, some of which are relatively soft and others are pre-packed, shaped boxes. Whichever is correct for the particular aircraft, it is essential that the user does not in any way interfere with the contents and packing, since they have been designed to transmit an acceptable ejection thrust. Similarly, unauthorised seat cushions should not be placed upon the seat pack, lest their characteristics alter the ejection accelerations and cause spinal damage. The contents of a seat pan, the back rest and seat harness form an intrinsic part of the whole ejection seat system and the characteristics of that seat are a reflection of the whole assembly and not just the ejection gun system.

EJECTION SEAT TRAINING

21. Practical seat ejection training must be carried out regularly in the seat specific to the aircraft in use and preferably in a representative work space. It should be carried out realistically and thoroughly, whilst wearing the complete personal flying clothing assembly which is normally used in the aircraft.

22. There has been a tendancy to limit ejection seat training to the emergency procedures required in the event of a failure of the normal automatic mechanism. It is equally important that emphasis is placed on practicing the normal firing drills, since any unnecessary time delay between deciding to eject and firing the seat can make all the difference between success and failure. Realistic practice, in a seat which has been made safe for training purposes, will also allow the user to assess the effort needed to operate the firing mechanism and to appreciate the time delays which may be built into the system. It is important that the individual adjusts the seat to his normal flying position so that he can learn the relative position of the firing handle and experience any difficulties involved in reaching it.

23. Aircrew should then practice any manual override procedures which are relevant to their particular seat. It is recommended that this part of the drill is carried out with the eyes closed in order to learn the procedures by touch, because of the possibility of night escape or interference with normal vision during the descent, because of rain or hail.

POST-EJECTION CONSIDERATIONS

24. Usually the acceleration during ejection is hardly noticed, but as soon as the seat is clear of the aircraft the occupant is exposed to other stresses which will now be discussed:

(a) WIND BLAST – When the seat clears the aircraft, the occupant is exposed to the ram effect of the slipstream. The magnitude of this effect varies with the air density and is thus related to the indicated airspeed (rather than true airspeed) and varies with the square of the velocity. It is therefore greater at high speeds and low altitude. At speeds up to 400 knots wind blast is unlikely to cause injury to the face, particularly if the face is covered; the oxygen mask prevents the entry of air into the lungs and stomach. Limb flailing is likely to be a more critical problem. As speeds continue to rise the effect of wind blast is one of the factors which may limit the usefulness of the open ejection seat.

(b) SUDDEN DECELERATION – On entering the slipstream, the seat and its occupant undergo a marked deceleration caused by the wind-drag. The higher the indicated air speed, the greater is the deceleration effect. For a given indicated air speed, the maximum linear decelerations are not affected by altitude but as the ejection altitude is increased, the deceleration time is more prolonged. This is due to the fact that for a given indicated air speed, increased altitude causes a greater kinetic energy which must be dissipated as a function of time in an atmosphere of lower density. Ejection seats are usually provided with some form of stabilization system so that this deceleration takes place in a relatively 'straight' line; an unstable seat system produces a complex variety of forces on the seat occupant. There are many factors which affect the drag characteristics of the man/seat complex and it is not possible to lay down a maximum indicated air speed for safe ejection. Assuming a maximum safe peak linear deceleration of 35 G, it has been calculated that this might be experienced at an indicated air speed between 600 and 700 knots.

(c) TUMBLING AND SPINNING – Unstable seats tumble and spin, causing high acceleration loads which can injure the occupant. For this reason ejection seats are usually stabilized during free fall. In some cases this only lasts for a short time, if the system is designed for the man to leave the seat shortly after ejection; in others the occupant carries out the free fall from high altitude in the seat.

(d) EFFECTS OF ENVIRONMENT AT HIGH ALTITUDE – If ejection takes place at an altitude above 3 000 m (10,000 ft) the opening of the man-carrying parachute is usually delayed until a predetermined altitude is reached, usually around that height. This is done to avoid high opening shock loads, hypoxia and the effects of low atmospheric temperature.

CONCLUSION

25. Some form of assisted escape is essential if high performance aircraft are to be abandoned successfully in emergency and many lives have been saved by this equipment. Aircrew should understand their ejection seat (or jettisonable cabin system) thoroughly and practise both the routine and emergency drills associated with their particular assembly. The significance of aircraft attitude as a factor in limiting the minimum safe altitude for successful escape cannot be over-stressed and aircrew must always bear this in mind when confronted with an emergency situation.

- **KNOW YOUR ESCAPE SYSTEM THOROUGHLY AND PRACTISE ACCORDINGLY.**
- **DO NOT INTERFERE WITH THE PACKING OR CONTENTS OF SEAT EQUIPMENT.**
- **ENSURE A GOOD EJECTION POSTURE FOR INJURY-FREE ESCAPE.**
- **DO NOT INCREASE PARACHUTE LANDING IMPACT BY LATE CANOPY ADJUSTMENTS.**
- **AIM TO COLLAPSE CANOPY AND FREE IT IMMEDIATELY ON LANDING.**

CHAPTER 17

SURVIVAL

INTRODUCTION

1. Aircrew who have to abandon their aircraft in an emergency may be immediately faced with a survival situation. The seriousness of their position and the particular problems which may arise, depend upon the prevailing circumstances. These will be influenced by: the amount of warning of the emergency, whether the escape takes place in flight or after emergency landing or ditching, the climatic conditions and the remoteness of the area.

2. Emergency escape from aircraft has already been discussed in Chapter 16. It is sufficient therefore to stress that the more successful this is, the better the survivor's mental and physical state and his preparation for any situation which may arise.

PRINCIPLES OF SURVIVAL

3. The main factors associated with successful survival are:
   (a) The will to survive.
   (b) 'Know-how'.
   (c) Protection from the environment.
   (d) Rapid location by search and rescue organisations.
   (e) The availability of water and food.

4. The will to survive is the first essential for success, whatever the circumstances, and 'know-how' greatly improves the chances in any kind of survival situation. The order of priority of the remaining three factors vary with the particular circumstances and these will be discussed in some detail when considering the various types of survival.

5. There are many cases on record of individuals who have survived the most extraordinary deprivations despite being 'equipped' only with the will to survive. It is equally true that no amount of training and survival equipment will bring a man through a survival situation if the will and confidence

are lacking. At the same time, these general principles are to some extent inter-related; aircrew survival training which provides the 'know-how' also helps to build up an individual's confidence in his own ability to cope with a survival problem. Experience and familiarity with all the aspects of survival help to raise an individual's morale when faced with a real situation, because he knows that he has succeeded before and can therefore do so again. Ignorance, fear and loneliness are all potential enemies in the struggle for survival; these can best be dispelled by a high standard of training and confidence.

6. Given then, that a member of aircrew faces a survival situation with a confident attitude of mind, there is no limit to his potential. By adherence to the other principles of survival, he will be able to help himself and his would-be rescuers.

7. This is not intended to be, nor can it be, a comprehensive treatise; rather is it an attempt to give examples which can be variously adapted with success. A wide variety of survival aids is available to aircrew in the different NATO Air Forces; therefore it is not possible to mention all of these and any reference to equipment will be made only to explain the application of a principle more clearly.

LAND SURVIVAL IN COLD CLIMATES

8. This does not refer solely to the problem of the Arctic or sub-Arctic, severe weather conditions can also occur in temperate climates.

(a) PROTECTION FROM THE ENVIRONMENT – The material available for personal protection or shelter will depend largely on the method of escape, access to aircraft wreckage and geographical position. Following a successful crash landing, rather than an in-flight escape, the problem is likely to be easier; not only will crew members be together, but the wreckage of the aircraft will supply many useful items in addition to the normal survival equipment. The following points should be borne in mind:

(1) Life-saving first-aid must be carried out immediately and injured members given emergency shelter whilst the general situation is being assessed.
(2) If the aircraft is nearby, engine oil for use as fuel should be drained out before it freezes or it may become impossible to recover.
(3) Other useful items of equipment should be salvaged from the aircraft.
(4) Preparation should then be made to provide shelter for the crew, bearing in mind the time available before nightfall. Even if the fuselage of the aircraft is intact it is not usually suitable as a shelter in very low temperatures, because it is difficult to keep warm in a bare metal box.
(5) Lean-to shelters, paratepees or snow trench shelters can be constructed according to the local situation; the importance of plenty of protection under the body, as well as shelter above it, should be remembered.
(6) Survivors should keep active when in the open but not get over-heated. For example, layers of clothing should be removed before beginning strenuous work and then replaced when finished; this avoids excessive sweating into the clothing which may freeze.
(7) The importance of the care of the feet cannot be over-emphasised because frostbite can occur very easily. The precautions are simple; shoes and socks should be removed periodically and the feet rubbed for 5 to 10 minutes to stimulate blood circulation. Spare socks should be kept next to the skin to keep them dry and a dry pair should be put on at least once a day. Outer footwear should be removed at night and kept inside the sleeping covers near the body, so that it doesn't freeze overnight.
(8) Preparation for rest should be made well before dusk falls. If there is no sleeping bag, parachute material and natural foliage are the next

best thing. Dinghy fabric, as a means of protection can be life-saving but it is impervious to moisture and condensation tends to cause dampness within.

(b) RAPID LOCATION – This comes high on the list of factors for early consideration because survivors should prepare, as soon as possible, to help search organisations. These are likely to be most active as soon as the emergency is established and survivors must be prepared for this or the chance of being found may be missed.

(1) Emergency radio transmitters should be used according to instructions and pyrotechnics and signalling mirrors kept close at hand. Care should be taken to ensure that all these items are kept in good order as long as possible.

(2) Preparation should be made to help search aircraft by means of signal fires and other ground markers, such as the letters SOS in a very large size, laid out in the open near the camp. The recognised international emergency code signals are shown in Fig.22.

(3) Survivors should not stray too far from camp without some means of signalling, lest a chance be lost.

(c) WATER – A supply of drinking water can be obtained from melted fresh water ice, old sea ice, or snow. Survivors should try to keep a quantity of water available, at all times.

(d) FOOD – Hot meals should be prepared as often as possible and survivors aim to have at least one hot meal per day. Survival rations should be carefully conserved and augmented from local sources.

9. The question of travel depends very much on circumstances, particularly early on when it is most likely that rescue will be forthcoming. If it is decided to 'walk out', it is important not to travel too far in any one day; survivors should also avoid sweating inside their clothing when on the march, getting too tired, and failing to get some form of camp organised before night fall.

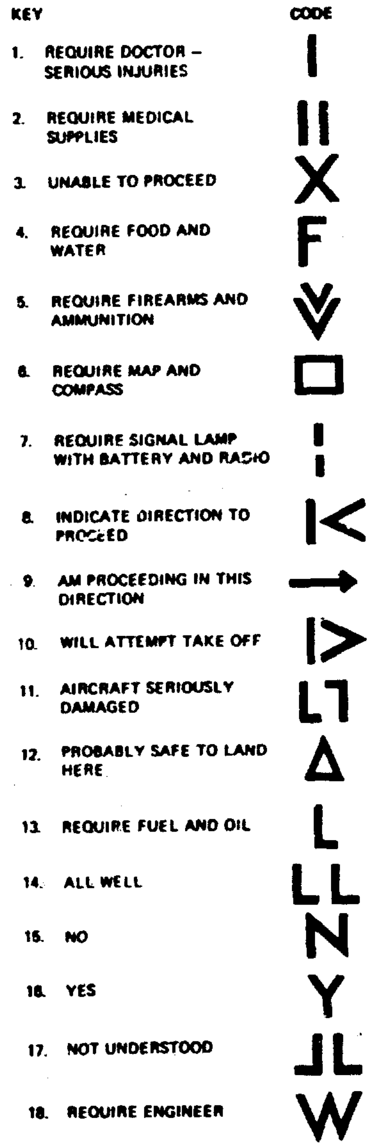


Fig.22 Emergency Signal Code

LAND SURVIVAL IN TEMPERATE CONDITIONS

10. Immediate protection from the environment is likely to be less urgent than in conditions of extreme cold and greater priority can be given to improving the chance of being located by search aircraft, which means that survivors should concentrate on the various aids to location.

11. Water and food are likely to be readily available and survival rations can therefore be kept in reserve as far as possible.

12. Travel is also likely to be easier in temperate climates but once more the decision to 'walk out' and when to do so, will depend upon local circumstances. Although temperatures will not be particularly low, care of the feet is no less important. They should be inspected at regular intervals, socks kept as dry as possible and changed frequently. It is very difficult to travel far on sore feet.

SURVIVAL IN DESERT CONDITIONS

13. If the crashed aircraft is nearby and it is safe to approach it, water must be salvaged before anything else. Water is vitally important and likely to be in such short supply that every care must be taken to minimise sweat loss through over-exertion.

(a) PROTECTION FROM THE ENVIRONMENT – Some form of shelter should be constructed to provide protection from the sun and as little work as possible carried out in the heat of the day. It may also be necessary to protect the eyes from glare and sand and this can be done by making simple eye shields. Sandstorms can spring up very quickly and survivors should be prepared to protect themselves from this hazard.

(b) RAPID LOCATION – All means of signalling to search aircraft should be used according to laid down procedures and ways of improving visual pick-up from the air should be made ready so that no opportunities of being seen by search aircraft are lost.

(c) WATER –

(1) Water conservation during desert survival is critical and begins by restricting water loss as much

as possible. Work should be confined to the cool hours and survivors remain in the shade, at rest, during the day.

(2) The complexity of factors affecting water discipline makes it difficult to formulate rules but, in general, drinking water should be rationed and the following arrangement is suggested: none for the first 24 hours, a third to half a litre (12–16 oz) daily taken in 5 or 6 portions. If this ration cannot be maintained it can be reduced to a quarter of a litre (8 ozs) but not lower, with the exception of the last quarter litre (8 ozs) which can be split to last 2 days. When this water ration is being taken it should be sipped slowly, wetting the mouth well before swallowing.

(3) Every opportunity should be taken to catch water from rainfall and collect it from early morning dew.

(4) Other sources of fluid may be found in certain areas. For example, in coastal areas, or near dried out desert lakes, there may still be water near the surface. Try digging a hole in the first depression behind the first sand dune and if you reach wet sand, water will collect in the hole. This is likely to be fresh rain water which will provide a life-saving addition to a meagre water supply.

JUNGLE SURVIVAL

14. In dense jungle, the problem for search aircraft and other rescue organisations is immensely difficult and survivors will probably be forced to travel in order to get help. Movement will be difficult through the dense undergrowth and direction must be checked frequently; it a stream or river can be found it should be followed since it may lead to habitation.

(a) PROTECTION FROM THE ENVIRONMENT – The biggest problem is likely to be from insects, ticks and leeches. The skin should be protected as much as possible by whatever equipment is available, such as netting and insect repellant. The body should be

inspected closely during rest stops and ticks and leeches removed, preferably by touching them with a hot ember. They must all be removed by whatever means, because they can weaken a person very rapidly by removing blood from his body. Body hygiene is very important (see Chapter 1); the body and clothing should be washed regularly to minimise skin infection, because of the many cuts and abrasions which occur during travel through the jungle, quite apart from insect bites. Infections which do occur should be treated with the antiseptic cream contained in first-aid kits, if these are available. The larger animals are unlikely to cause trouble unless disturbed. For example, snake-bite is uncommon and when it does occur, death is rare. The commonest effects of snake-bite are fright and fear of death. This calls for continual reassurance, immediate action to clean out the wound and treatment with antiseptics.

(b) RAPID LOCATION – Means of signalling should always be kept readily available although the denseness of jungle foliage restricts the methods of communication which can be used effectively.

(c) WATER –

(1) Water is likely to be reasonably plentiful from small streams but should be purified whenever possible. Salt depletion may become a problem, due to excessive sweating. If available, salt should be added to the diet from a supply contained in the survival equipment, bearing in mind that salt tablets should not be consumed whole because they are badly absorbed.

(2) Vines provide a valuable source of water; they should first be cut near the ground and when a container has been placed under the cut end the vine should then be cut off as high as possible and supported whilst the water drains out of the lower end into the container.

(d) FOOD – A survivor should try to live off the land and conserve his emergency rations.

15. After landing in water, the immediate problem is getting into the dinghy; this will be made more difficult if the water temperature is low and the sea is rough. It will be made easier if the survivor is well practised in his procedures, is able to swim (since he will be more at home in the water) and if he is wearing the appropriate flotation gear and protective clothing. Having established himself safely in the dinghy, the subsequent priorities are based on the usual principles of survival:

(a) PROTECTION FROM THE ENVIRONMENT –

(1) The dinghy becomes the primary means of protecting a survivor from his environment. The various items of protective clothing which safeguarded the aviator when he was in the water will provide extra protection from the cold since they will keep him afloat and protect him from low sea temperatures.

(2) When settled in the dinghy and before any protective apron has been closed, the inside of the dinghy should be made as dry as possible. It should be baled out and inspected closely for leaks which must be sealed.

(3) In high ambient temperatures the occupant of a dinghy should protect himself from the sun by rigging up some kind of screen or he will become severely dehydrated and burned.

(b) RAPID LOCATION – Emergency radio equipment should be prepared for use according to local regulations; other signalling devices checked and kept ready for use. Signal cartridges are particularly useful, also dye marker and a heliograph.

(c) WATER REQUIREMENTS – Because of the hazard of drinking salt water, the provision of a fresh water supply will become the main problem during prolonged sea survival. The recommended minimum water intake is based on the principle of keeping fit and alert in the early days when search aircraft and vessels are likely to be most active. At least half a litre

(approximately 1 pint) a day is desirable, particularly in high temperatures or if the survivor is injured or losing body fluid due to vomiting. It may, however, be necessary to restrict this intake in other circumstances and the following routine is recommended: none on the first day, one third to one half litre (15–20 ozs) on subsequent days when water is still reasonably plentiful, reduced to a few sips each day when there is only half a litre of water left. Neither sea-water nor urine should be consumed; sea-water is dangerous because the kidneys cannot pass strong salt solutions (see sub-paragraph 4) and the urine of a dehydrated man is already maximally concentrated and cannot provide further free water. For this reason, one should never drink sea-water (see sub-paragraph 4). The conservation of water is always a critical factor and survivors should aim to waste as little water as possible, rather than drinking less. The dangers of a lack of water are great, producing fatigue, thirst, heat oppression, nausea and headache. The various factors which influence a survivor's fluid requirements are as follows:

(1) The larger the individual the greater amount of fluid he needs.

(2) The body should be kept as cool as possible to reduce fluid loss. In hot conditions a large quantity of fluid can be lost through sweat; this must be prevented by reducing exercise to a minimum, the maximum use of shade, and improving body cooling by dampening the clothing regularly with sea-water.

(3) It has already been pointed out that vomiting causes fluid loss and seasickness can therefore have serious implications when water is in short supply. Sea survivors are therefore strongly recommended to take anti-seasickness pills in the early stages; these are usually supplied in the survival or first aid packs.

(4) On average, the total salt content of sea water is 3.5 g per 100 ml and the maximum concentration of sodium chloride which the kidneys can achieve

in urine is only 2 g per 100 ml. Therefore quite apart from the normal work of the kidney in ridding the body of salts it couldn't even cope with sea water alone. The body would therefore have to use up extra tissue fluid to help remove the sodium chloride, or else retain the salt. Either result would be harmful and reduce the chances of survival. Even the consumption of diluted sea water is dangerous because the kidney has an increased problem in excreting salts in the survival situation. Sea-water should never be consumed therefore.

(d) SOURCES OF WATER – There are fortunately a number of possible sources of fresh water available to the sea survivor and every effort must be made to keep plenty of fresh water in hand as well as drinking an adequate amount:

(1) Rainwater – Survivors should be ready to collect every bit of rainwater they can. This source, if available, should be used first to provide the daily ration.

(2) Solar Stills – A solar still is a means of producing fresh water from sea water by means of distillation brought about by sunlight. Equipment of this type is frequently included in survival equipment. It requires reasonable climatic conditions and some patience on the part of the user, but it has the great advantage that it can be used indefinitely.

(3) Chemical Desalters – Chemical desalters produce fresh water from salt water but can only be used once. The amount of water which can be produced by them depends on the amount of chemical contained in the survival pack.

(4) Survival Pack – There is likely to be a supply of fresh water in the survival pack but every effort should be made to obtain drinking water from the various sources which may already have been mentioned.

(e) FOOD – When water is in short supply, carbohydrate foods are recommended. Small quantities of

fat and protein may be taken but large quantities of these foods increase the need for water. Survivors will usually be supplied with fishing gear and should make every effort to augment their diet by catching fish. Survivors should bear in mind however, that thirst and dehydration are more important factors than hunger and starvation.

CONCLUSION

16. A survivor has every likelihood of success if he shows determination and ingenuity. His chances are greatly improved if he starts with all his protective clothing and survival gear, together with the knowledge of how to use these and having practised the various techniques during previous survival training.

17. Aircrew should not, however, load themselves with survival aids over and above those supplied as part of their emergency equipment. An overabundance can adversely affect the chances of successful escape from the aircraft; in particular, the increased weight can impede seat ejection and seriously impair flotation during sea survival. Ultimately, the will to survive and 'know how' are the most important survival aids, together with confidence and a common sense approach to the task in hand, however difficult it may at first seem.

- **KNOW THE PRINCIPLES OF SURVIVAL AND APPLY THEM WITH CONFIDENCE.**
- **TAKE EVERY OPPORTUNITY FOR SURVIVAL TRAINING.**
- **FAMILIARISE YOURSELF WITH ALL THE AIDS YOU CARRY.**
- **LEARN ABOUT THE TERRAIN YOU ARE FLYING OVER.**
- **CONSERVE WATER IF IN SHORT SUPPLY; NEVER DRINK SEAWATER.**

CHAPTER 18

FIRST-AID

INTRODUCTION

1. Accidents can and do occur at any place and any time. They occur without warning and a bystander is confronted with an urgent and critical situation. You might very well be that bystander one day and the life of injured people may depend on your ability to cope. You must know exactly what to do and have practised the various techniques involved, before that emergency arises. Time saved can well mean a life saved.

2. It is essential to have a clear idea of priorities so that urgent life-saving action is taken promptly and effectively. For example, when you are confronted with a casualty who has multiple injuries, those which are most obvious may not be the most serious. It is also important to remember that only essential life-saving measures should be carried out when expert help is within easy reach, otherwise valuable time will be wasted before getting the injured to a hospital or other suitably qualified help.

3. Some general first-aid information has also been included in this chapter to help you to deal with a variety of injuries which you might be faced with in a survival situation when there is no immediate hope of getting expert help.

BASIC PRINCIPLES OF FIRST-AID

4. There are certain basic essentials which must be kept in mind when dealing with a casualty and these will be discussed in their general order of priority. Some of these may not be relevant to a particular situation but the reasoning behind them will soon become obvious and allow you to fit each case into its correct place. Armed with this knowledge you will then be able to appraise individual emergencies quickly and take the correct action. The main

points to consider when confronted with a casualty are as follows:–

(a) SAFETY OF THE CASUALTY – A casualty may be found in a position in which he is still in danger, for example, in a fire or in contact with high voltage current. Clearly he must be removed from the hazard as quickly as possible, but the rescuer should take precautions to ensure that he is himself not incapacitated. Speedy recovery and recklessness are not synonymous: a little thought will ensure maximum safety and efficiency even under difficult circumstances. The rescuer should also bear in mind the possibility of the existence of potentially lethal weapons such as ejection seat guns, ammunition and so on at the scene of the accident. When moving a casualty, remember that every care must be taken to minimise the possibility of aggravating existing injuries and where no hazard exists to either casualty or rescuer do not move the casualty unnecessarily.

(b) CONFIRM THAT CASUALTY IS BREATHING – Always check first that a casualty is breathing; if he is not the airway to his lungs should be re-established (see paragraph 8) and if this does not start his breathing, artificial respiration must be given immediately (see paragraph 9).

(c) CHECK FOR HEART BEAT – When confirming that the casualty is breathing it is also important to check that his heart is beating. Failure of the heartbeat is not synonymous with death and the circulation can be restored if the correct action is taken at once (see paragraph 14).

(d) CARE OF THE UNCONSCIOUS – If the casualty is unconscious, it is essential to lay him flat and ensure that, when you are not actively carrying out resuscitation, he is placed in such a position that he will not suffocate. This is achieved by securing him in a semi-prone position so that his breathing is not obstructed either by his tongue falling back into his throat or by stomach contents if he should vomit (see paragraph 17). An unconscious casualty may be found

trapped in a sitting or standing position and it is essential that he is laid down as soon as possible. If not, he may receive brain damage due to the already poor blood circulation to the head being further embarrassed by the effects of gravity; it is also important to correct the posture of an unconscious casualty who is found head down.

(e) SEVERE BLEEDING – Severe bleeding must be stopped as soon as possible, by applying firm external pressure over the bleeding point and if a limb is involved, by raising it well above heart level.

LIFE-SAVING TECHNIQUES AND MANAGEMENT OF CASUALTIES

5. Having enumerated the general principles of first-aid and the various priorities which must be considered when you first assess a particular casualty, it is now appropriate to look at these life-saving techniques in some detail, so that you will be able to carry them out quickly and efficiently. These procedures include resuscitation, the control of severe bleeding and the care of the unconscious casualty.

RESUSCITATION

6. The main resuscitation techniques are concerned with the restoration of breathing and the heart's action. Whether or not a casualty is breathing can be checked by looking for movement of his chest or the upper part of his abdomen and listening for breath sounds at his mouth and nose.

ARTIFICIAL RESPIRATION

7. If a casualty is not breathing, artificial respiration must be started immediately. Although there are many methods of performing artificial respiration, only 'exhaled air respiration', commonly known as the 'kiss of life', will be described, because it is the most effective and convenient method under all circumstances. It is worth noting that when rescuing a casualty in water it is not only possible but desirable to perform an occasional cycle of exhaled air respiration on the way to the shore. This particular techn que is possible even when swimming and the time saved could be critical.

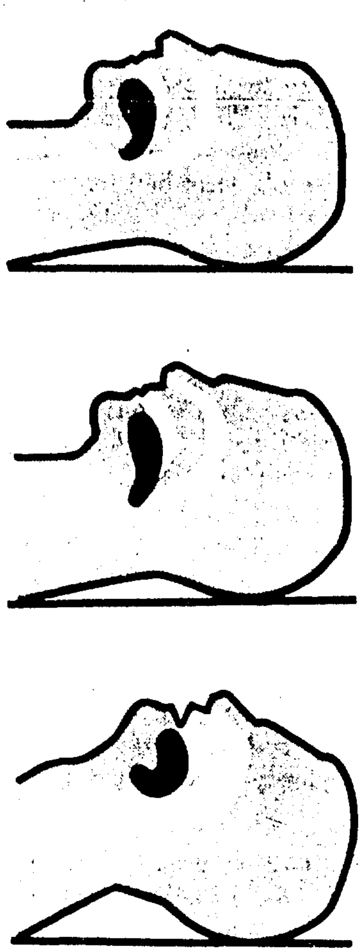
CLEARING THE AIRWAY

8. Before exhaled air respiration can begin the casualty's airway must be cleared so that there is a free passage-way for air to get into his lungs. This can be done whilst he is lying in the semi-prone 'unconscious position', described in paragraph 17, or when he is lying on his back. Firstly, remove any obstruction from his mouth or throat (e.g. dentures, vomit or debris) and pull his tongue forward. Next, his head should be placed in such a position that the main air passages to his lungs are opened up widely. This is done by tilting his head back as far as possible and pulling his chin forward (see Fig.23). In many cases, respiration will begin spontaneously once this has been done, but if not, artificial respiration must be started immediately.

EXHALED AIR RESPIRATION

9. Exhaled air respiration involves inflating the casualty's lungs at regular intervals by means of the rescuer's exhaled breath; entry into the lungs being gained either through the casualty's mouth or nose or in the case of a small child, both at once. This technique is based on the fact that exhaled air contains between 17 to 18% oxygen, compared with the 21% in atmospheric air, so there is plenty of oxygen for the casualty.

10. To carry out the 'kiss of life' turn the casualty onto his back and open his mouth, keeping his head in the position which maintains a good airway. Whilst you are taking these actions kneel alongside the casualty, at the level of his head, in such a way that you can carry out the breathing manoeuvre easily and comfortably. Take a breath in, place your open mouth over the casualty's and at the same time, close his nostrils with the finger of one hand, keeping his head back and jaw forward with the other (see Fig.24). Exhale firmly into his mouth, whilst checking for chest expansion which shows that the exhaled air has entered his lungs. There is no need to exhale very deeply to achieve satisfactory inflation of his lungs. At the end of a normal, not forced expiration, remove your mouth well clear of his



(a) This diagram shows a normal clear airway in a conscious person.

(b) When a person is unconscious the tongue is likely to fall back and block the throat.

(c) When the head and neck are extended, jaw forward, the airway is both clear and enlarged.

Fig.23 Clear Airway to the Lungs

and take another breath in. This completes one respiratory cycle and after a short pause the whole procedure should be repeated. Aim to carry out this manoeuvre rhythmically, about every six seconds, until the casualty starts to breathe of his own accord. The timing is not critical however; when his chest has emptied, fill it up again. Remember that the effectiveness of this procedure depends upon maintaining a satisfactory airway so, at all times, his head and jaw must be held in a good position.

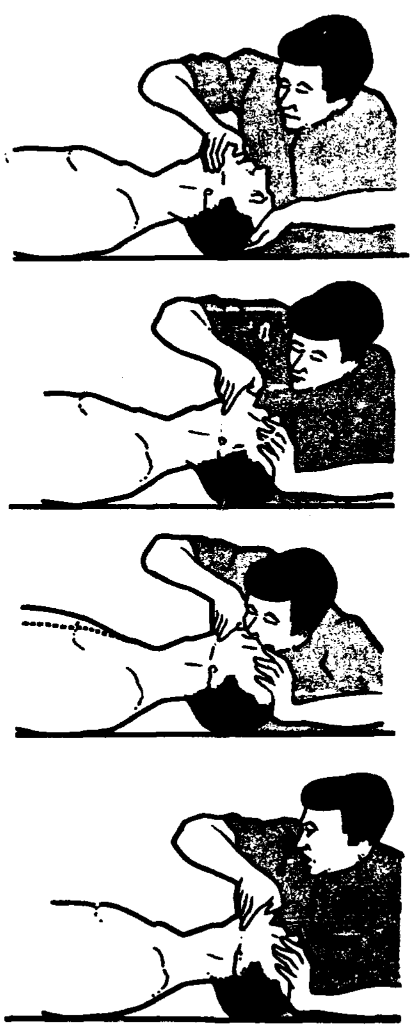
11. In paragraph 9 it was pointed out that this technique could be used either through the casualty's mouth or nose. But the description so far has been concerned with 'mouth-to-mouth' breathing. It is useful to remember the other route, however and you should use whichever is easier and more effective. If the nose is used, remember that the head and lower jaw positions are still critical, but this time his lips must be kept closed instead of pinching his nose.

12. Before artificial respiration is begun, the person's skin and particularly his lips and ear-lobes have a bluish colour, (instead of the usual healthy pink), because his blood is not being recharged with oxygen. After some six to eight cycles of artificial respiration the pink colouration should return, as his blood becomes oxygenated by the rescuer's expired breath. Artificial respiration should be continued, however, until he starts to breathe spontaneously. The casualty may still remain unconscious after his breathing has restarted so that it is important to replace him in the semi-prone position (see paragraph 17).

13. If there is no improvement in the colour of the casualty's skin after six to eight cycles of artificial respiration, his heart may have stopped beating. This can be checked by feeling for a pulsation at the side of his neck (carotid artery), in either temple or on the bare chest over the heart just below the left nipple, (these areas are more convenient to reach than the radial pulse in the wrist). If a pulsation cannot be felt in any of these sites and if the pupils of his eyes are wide open, it is likely that his circulation has stopped. In such a situation, the rescuer is faced with trying to re-start his heart beat by the method known as 'external cardiac massage'.

EXTERNAL CARDIAC MASSAGE

14. External cardiac massage denotes a rhythmic squeezing of the heart, between the front and back walls of the rib-cage, by means of external pressure applied to the front of the chest. This means that it can only be carried out effectively if the casualty is lying on his back on a firm surface. The rescuer then adopts a kneeling position beside



(a) Extending head and neck to clear airway, having removed any obstructions from the mouth.

(b) Lifting jaw forward and pinching nose, whilst inhaling in preparation to give the 'kiss of life'.

(c) Rescuer breathing slowly into the casualty's mouth; watching the chest expand as the lungs fill with air.

(d) Rescuer relaxing and inhaling, watching the casualty's chest fall as he exhales.

Note: (1) If the chest does not rise and fall during exhaled air respiration, check the position of the casualty's head and jaw.
(2) Continue exhaled air respiration until casualty breathes spontaneously or for at least an hour.
(3) In 'mouth-to-nose' respiration, seal the casualty's lips with the hand which is supporting his chin.

Fig.24 Exhaled Air Respiration

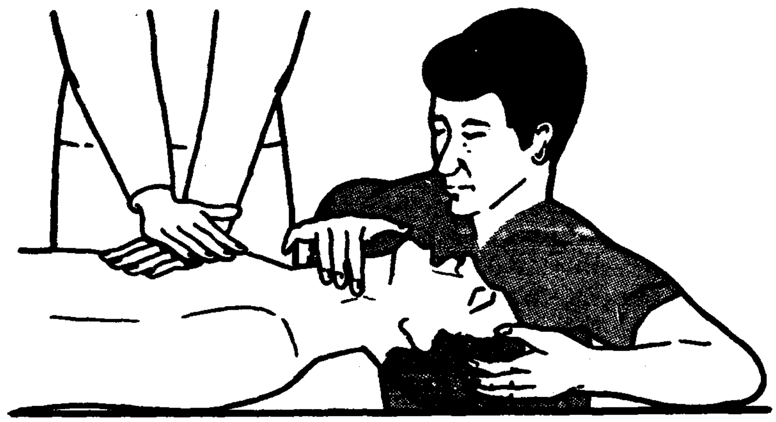
him with his hands, one on top of the other, placed over the lower part of the casualty's chest, ready to begin heart massage. The squeezing action entails considerable effort and must be repeated rhythmically. It is best done by allowing your weight to bear down sharply so that your hands depress the lower part of his breast-bone about 2.5 to 4.0 cm (1 to 1½ in), then leaning back to release the pressure. The amount of effort which is required to carry out this very tiring procedure makes it necessary to use the weight of the trunk, keeping the arms straight; it would be virtually impossible to achieve the correct action with arm movement alone (see Fig.25). The whole cycle has to be repeated and continued once every second.

15. If there are two of you available, one should carry out exhaled air respiration whilst the other is performing external cardiac massage. If not, then you must carry out both manoeuvres yourself in a set sequence. After each six cycles of massage, perform one cycle of exhaled air respiration, followed by six more of massage and so on. As soon as the heart starts to beat and the circulation has been restored, artificial respiration alone should be carried out until breathing has restarted naturally. The casualty should once more be placed in the semi-prone position and kept under close observation.

16. Practice helps to prepare you for having to carry out external cardiac massage in an emergency. A word of warning is necessary however! Whereas it is safe enough to practice exhaled air respiration on a willing subject, external cardiac massage must only be practiced on a suitable dummy figure, because the chest compression could be dangerous to a healthy person.

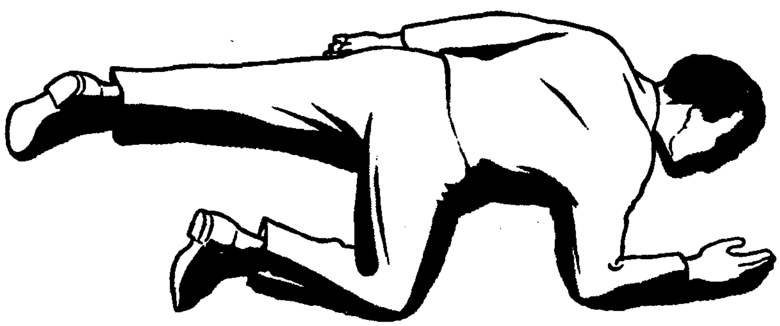
THE UNCONSCIOUS CASUALTY

17. Frequent reference has already been made to the importance of placing an unconscious person in the 'semi-prone position' if he has to be left unattended temporarily. It is important to stress, however, that you must never leave a casualty until you are satisfied that he is breathing



Initiate external cardiac massage when there is no sign of blood circulation; bear in mind the need to maintain a good airway and satisfactory ventilation of the lungs.

Fig.25 External Cardiac Massage



Never leave an unconscious casualty unless it is absolutely necessary and if you do so, always ensure that he is stabilised in the 'unconscious position' so that his airway is unlikely to become obstructed.

Fig.26 The Unconscious Casualty

satisfactorily and that his heart and circulation are functioning. Then, if you must leave him, make sure that he cannot come to any harm and this is done by placing him in the 'semi-prone position' (see Fig.26). The purpose of this position is to prevent his airway becoming obstructed by his tongue falling back into his throat, or stomach contents being inhaled if he should vomit. As you can see from the diagram, the casualty's position is stabilised by placing one of his arms immediately behind him, to prevent him rolling on to his back. For the same reason, the other arm is outstretched and the leg which is uppermost is flexed and positioned forward of his other leg. If possible, it is ideal to position his whole body in such a way that his head is at a lower level than his feet (i.e. on sloping ground it would be desirable to so place him that his head should be slightly down hill). This position helps his blood circulation and makes it less likely that his throat will become blocked. You should, of course, remove any obstruction from his mouth just as you would before performing artificial respiration. Clothing around his neck should be loosened and his body should be covered lightly if he is likely to get cold.

18. Finally, ask youself if it is really necessary to leave him and then do so only if you have checked his colour, respiration and circulation and you can be sure that he is as fit and as safe as you can make him.

CONTROL OF SEVERE BLEEDING

19. Severe bleeding is obviously dangerous, since the loss of large quantities of circulating blood deprives the tissue of the oxygen which is necessary to maintain life and function. It is important, therefore, for you to act speedily and efficiently to restrict blood loss to the minimum. The treatment of bleeding will be considered according to whether it is external or internal. External bleeding, as the name suggests, implies that blood is escaping directly from a wound to the outside of the body, whereas internal bleeding denotes that the haemorrhage is within the body. The latter is usually hidden, of course, but may become visible if for example some of the blood is coughed up or vomited.

(a) EXTERNAL BLEEDING – This is stopped by applying firm pressure directly over the bleeding area. Ideally you should use a sterile first-aid dressing, but if this is not readily available do not waste time in searching. Any suitable piece of clothing rolled into a pad, or even your bare hands, can be used. When bleeding is severe, the essential thing is to act quickly; you can always dress and bandage the wound later. If the bleeding does not stop, add another pad and exert more pressure. Do not remove the original pad as this will only disturb the wound and make matters worse by disrupting any blood clots which are beginning to form. For the same reason, the casualty should be kept as still as possible and the wounded area immobilized. If you are dealing with a limb, raise it as high as possible above the level of the heart and this will help to stop the bleeding more quickly. Tourniquets have not been mentioned in the treatment of bleeding, however severe, because they are difficult to use correctly and if improperly applied can do more harm than good. Pressure and elevation are all that is required.

(b) INTERNAL BLEEDING – If a casualty looks pale, anxious and ill, with a rapid feeble pulse but no outward sign of severe injury, you suspect that there is internal bleeding. Under such circumstances try to get expert help as soon as possible. In the meantime the patient should be disturbed as little as possible and not given anything by mouth.

REASSESS THE SITUATION

20. Now is the time to reassess the situation. The casualty has been removed from danger; his breathing and circulation are functioning; he is not bleeding seriously and if unconscious, he has been placed in such a position that he can come to no harm. Having satisfactorily dealt with all these emergency situations, the rescuer should now deal with other injuries which the casualty may have sustained. The amount and type of treatment which is given will depend very largely on whether or not skilled help is close at hand.

TREATMENT OF WOUNDS

21. Having stopped any severe bleeding from a wound, or if the wound is of a minor nature, the next consideration is to protect it from further damage or becoming infected. Wherever possible it should be covered with a sterile dressing but if these are not available you must improvise as best you can, using the cleanest material available. Having covered the wound, the dressing should be held on by firm but not tight bandages. If the casualty has to be moved, the wound area should be well padded to give added protection.

IMMOBILIZATION OF FRACTURES AND DISLOCATIONS

22. A fracture or dislocation is usually obvious because of the pain and deformity associated with it. If you are in any doubt, however, assume the worst and do not manipulate the part in any way to confirm your suspicions; nor should you try to straighten a deformed limb. Treatment consists of immobilizing the area to prevent further pain and damage. If a limb is involved, not only the site of the fracture but also the natural joint both above and below should be immobilized. The damaged area should be well-padded for maximum protection and limbs should be splinted with any material available. An undamaged leg can form an excellent splint for the injured one and equally, a broken arm can be supported by securing it across the front of the body.

HEAD INJURIES

23. Casualties with severe head injuries are likely to be unconscious. Your primary consideration, therefore, is to ensure that respiration and circulation are maintained and that the person is placed in a safe posture. Watch him carefully and note the amount of time that he remains unconscious; you should also observe how responsive he is when he regains consciousness. These points can be of great help to the physician when he takes over the care and treatment of the patient. Until skilled help is available keep him as quiet and comfortable as you can and when his consciousness returns do whatever you can to reassure him.

BURNS

24. The treatment of a burn is aimed at preventing further damage to the area; reducing the risk of entry of infection and keeping the fluid loss from the burned area to a minimum. The first-aid treatment of severe burns is characterised much more by the things which should not be done, rather than by active intervention on the part of the first-aider. The use of dry dressings, if possible sterile, is sufficient. If these are not available, however, make use of a towel, sheet, piece of shirt, or any other clean cloth which may be available. This dressing should be fairly thick and kept in place by a lightly applied bandage. Once the dressing has been applied it should not be taken off until the casualty has been placed in the care of expert medical help. Do not apply ointment or greasy substances to the burned area because these will have to be removed before the physician can carry out the correct treatment and this added factor will introduce delays or complications. Do not remove more of the casualty's clothing than is necessary and if his clothing is sticking to the burn do not disturb it; simply cut the clothing round it and on no account attempt to pull it off. Do not try to clean the burn before applying the dressing and if there are blisters present do not puncture them.

25. Burned extremities can be treated effectively by immersing them in cold, clean water. This lowers the local skin temperature and reduces pain. If a burn has been caused by a strong acid or alkali the affected area should be bathed with large quantities of water if this is available and then the burned area should be treated as has been described for other burns.

CHEST AND ABDOMINAL WOUNDS

26. Major wounds in the chest and abdomen should be treated like any other wounds simply by covering and protecting the wounded areas.

TREATMENT OF SHOCK

27. Shock refers to a specific medical condition resulting from a combination of physical and nervous reaction to the accident and may or may not be associated with actual injury. A shocked casualty looks pale and even grey in colour; beads of perspiration may be seen on his forehead but nevertheless it feels cold to the touch. His pulse rate becomes rapid but weak and his respiration is often shallow and rapid. He is generally anxious and restless although at a later stage may become weak and listless.

28. The reason why shock has not been mentioned before now in a chapter on first-aid is that the treatment of this condition mainly takes the form of treating the casualty's injuries and reassuring him as much as possible. These main points have already been covered and thus the treatment of shock has mostly been taken care of already.

29. A shocked patient is both anxious and frightened, thus it is important to stress the need to handle him confidently and efficiently and to be kind and gentle in dealing with his injuries. Efforts such as these go a long way toward reassuring him and allaying his fears. He should be kept quiet and if he is lying in an exposed place, he should be protected from the rigours of the environment but must not be over-heated. Excessive layers of clothing and, for example, the application of hot-water bottles may well aggravate his shock by causing extra fluid loss through perspiration. These are very important points because the main cause of shock in severely injured people is fluid loss and the associated effect that this has on the circulation. For this reason, it helps to position the patient in such a way that his head is low and his feet are raised.

30. As a general principle, a casualty should not be given anything by mouth. An exception may be made in the case of a fully conscious patient whose only injury is due to burns. Even in these cases one should keep in mind the possibility of his receiving a general anaesthetic shortly, in which case it would be better not to give him anything to drink. Do not forget, however, that a patient can be

considerably comforted simply by moistening his lips with a wet cloth and by sponging his face if he is warm and distressed.

31. Pain is obviously a major contributory factor to the patient's shocked condition and if help is not forthcoming for many hours a conscious patient can be given pain-killing drugs, if these are available. This is another example of the basic underlying philosophy that all the measures which are taken to comfort and protect the patient are at the same time helping to alleviate his state of shock.

THE USE OF FIRST-AID KITS

32. Little or no mention has been made of first-aid kits because of the wide variety of drugs and equipment which might be available to you. The use of these kits will be dictated by circumstances and their contents should be used as adjuncts to the treatment which has been recommended. In general, drugs should be used sparingly, particularly if skilled help is likely to be available soon. You must, however, be familiar with the contents of your first-aid kits and know when and how to use them. In a survival situation, in particular, you may be forced into dealing with casualties over a lengthy period of time and this would influence your decisions governing the use of pain-killing drugs and tablets for the treatment of infections. This in fact denotes a stage of treatment which is beyond the more limited field of life-saving first-aid.

SUMMARY

29. Familiarise yourself with these life-saving principles and practice the various techniques involved when the opportunity arises. Thus you will be prepared to act quickly and efficiently when you are suddenly confronted with casualties. Remember that you should not be over-ambitious; stick to the main principles of saving life and preventing further injury. Always treat your casualty with confidence, assurance and compassion.

- ASSESS THE CASUALTY'S OVERALL CONDITION.
- DEDUCE PRIORITIES OF LIFE-SAVING MANOEUVRES.
- ALWAYS REMEMBER RESPIRATION, CIRCULATION, HAEMORRHAGE.
- TAKE CARE THAT THE UNCONSCIOUS PERSON IS SAFE.
- DO NOT MOVE A CASUALTY UNNECESSARILY.
- DO NOT GIVE ANYTHING BY MOUTH IF HELP IS AVAILABLE.
- BE KIND AND CONFIDENT BUT NOT OVER-AMBITIOUS.

CHAPTER 19

FLYING CLOTHING

INTRODUCTION

1. Leaving aside whims of fashion, the primary purpose of clothing has always been to protect the body from the unfavourable effects of the environment. The characteristics of a particular occupation have further led to the development of clothing best suited to its needs. Flying clothing follows these general rules; its purpose is to provide comparatively constant and agreeable conditions next to the skin (microclimate) and to supplement cabin conditioning. It also provides the wearer with whatever special services are needed, either in routine flight or emergency, without unduly restricting body movement. These basic principles provide clues to the design requirement of ideal flying clothing.

PRINCIPLES INVOLVED IN AIRCREW PROTECTION

2. The flying clothing for a specific aircraft is chosen to suit the role, geographical area of operation, and the layout of a particular crew station. This means that there is a wide range of assemblies of vastly differing complexity; from a simple coverall for a light aircraft, to the conditioned pressure clothing worn by high altitude aircrews and it is essential to be correctly clothed for the particular aircraft, environment and geographical area. In view of the great variety of flying clothing which is used in the various NATO air forces, it is not possible to discuss individual items in detail; nor is this necessary since there are other publications for this purpose. However, typical example of modern flying clothing are shown in the photographs in this chapter, together with short descriptions in paragraphs 14a to 14j.

3. In order to provide satisfactory aircrew protection, it is necessary to meet certain basic specifications which are as follows:–

(a) The clothing should be designed to suit the needs of the individual's primary task in the aircraft and

interfere as little as possible with his movement, either when seated or as a moving crew member.

(b) The assembly should provide protection in the event of any emergency which can reasonably be expected to occur in flight.

(c) In the event of an emergency escape from the aircraft in flight, the aircrew member should be protected during the appropriate escape manoeuvre, subsequent free-fall and parachute descent (see Chapter 16).

(d) The needs of survival should then be met, bearing in mind the possibility of sea survival and the widely differing types of terrain over which a modern aircraft can fly in one sortie (see Chapter 17).

(e) It may be necessary to consider the needs of evasion and escape. This can lead to difficulties in choosing the colour of clothing material since there will be a conflict between the needs of camouflage and easy recognition (see Chapter 14).

(f) In view of the flexibility which is expected of modern aircrew and the possible need to operate from advanced tactical bases, certain items of flying clothing may have to be worn on the ground between flights. This dual function is only practical with simple coveralls and not with complex garments designed to offer protection in extreme situations.

(g) The requirements of each air force will have to be met from the point of view of uniform style and acceptability, together with exacting international regulations concerning military dress.

4. In the past, 'flying clothing' referred mainly to outer garments but more recently the importance of the design and texture of undergarments has also received attention. There are advantages in designing a flying clothing assembly from the skin outwards, to provide maximum comfort and efficiency as well as to ensure that the various layers are compatible. Flying gloves and boots also require special attention to meet the demands of modern high performance aircraft.

5. The designer of flying clothing has a very difficult task in trying to meet all these various requirements. The finished aircrew equipment assembly is inevitably a compromise which tries to satisfy as many of these needs as possible.

INTEGRATION OF FLYING CLOTHING AND PROTECTIVE ASSEMBLIES

6. The flying clothing assembly is intimately related to whatever personal protective assemblies are required. In some cases combined garments are provided; in others, items such as pressure clothing remain separate, but are designed so that the whole aircrew equipment assembly acts as a complex functional unit. Items of protective clothing which are used by aircrew are: a protective helmet, oxygen equipment and in some cases pressure clothing, anti-G suit, flotation gear and immersion unit.

7. These items of protective clothing add considerably to the wearer's heat-load, because they are often made of rubberised fabric or contain rubber bladders. The nature of these garments particularly those with close-fitting cuff and neck seal, tends to create a microclimate which is isolated from the cabin air. In such cases, even the most efficient cabin conditioning system can do little to alleviate the heat load and a personal cooling and ventilating system becomes necessary (see Chapter 9).

THE FIT OF PERSONAL ASSEMBLIES

8. Flying clothing and personal protective assemblies are manufactured to meet a range of body sizes, based on current anthropometric data derived from measurements of a typical aircrew population. In exceptional cases where an individual cannot be fitted satisfactorily from the normal size range and if the garment is one which requires a critical fit then it may be necessary to provide a special item.

9. Before enlarging on the subject of fit, it is important to stress that the comfort of the wearer should always be the overriding factor. This must not be sacrificed at any stage

of the fitting process, otherwise the discomfort will lead to personal inefficiency or to the wearer himself altering the fit later to achieve comfort, at the expense of some degree of protection: either of these situations can be dangerous. It is therefore important to wear all the equipment for some time, both on the ground and in the aircraft workspace, to ensure that it is comfortable and fits well, before wearing it in the air for the first time.

10. Certain items of equipment need to be more close-fitting than others. For example, the anti-G suit and any other garment which contains gas-filled bladders should be reasonably form-fitting in order to keep inflation times down and reduce the inflated bulk. These garments should not however be too tight since comfort and normal function must not be jeopardised. The fit of a simple coverall is less critical and the size need only be limited by the need to avoid snagging due to loose material, personal comfort, and smartness.

11. It is particularly important to ensure that a protective helmet fits well. An uncomfortable helmet can be very distracting and in time this can reduce the wearer's performance to such an extent that it can cause an accident. A helmet may well feel comfortable but in order to protect the skull it should also fit uniformly around the head which means that the lining, or inner suspension harness, must be correctly located. The helmet will only absorb blows efficiently when it is correctly sized and fitted.

MAINTENANCE AND FUNCTIONAL CHECKS

12. Trained specialists will be available to maintain all items of flying clothing and safety equipment, nevertheless, aircrew are strongly encouraged to take a personal interest in their own equipment. Flying clothing plays a significant part in the successful outcome of a mission and in emergency, can make the difference between life and death.

13. In order to ensure trouble-free use, the appropriate inspections and functional checks should be carried out regularly on all items of equipment. Test schedules are laid

down for all personal equipment whose functional integrity needs to be checked. Certain of these are the responsibility of the aircrew and should be carried out correctly and thoroughly, otherwise avoidable failures will occur.

EXAMPLES OF FLYING CLOTHING

14. A number of typical items of flying clothing will now be described and examples of these can be seen in the appropriate photographs at the end of this chapter:

(a) FLYING OVERALL (COVERALL) – This is made in different materials and weaves, according to the thermal load and varies from a lightweight cellular cotton fabric in hot climates to a much heavier weight man-made fibre in cold/temperate areas. It is usually a one-piece garment and provides a variety of different pockets for the storage of maps and equipment (see Plates 1 and 7).

(b) COLD WEATHER FLYING CLOTHING – Is provided for crews operating in very low temperature areas and is necessarily a relatively bulky item. The insulation may be measured in 'clo units', (a clo unit is roughly the insulation value of the clothing worn by men in a temperate zone in the warm part of the year). The limit of clothing insulation is of the order of 4 clo, by virtue of the thickness (about 25mm or 1 in), bulk and weight which is necessary to achieve that value. An example of a current cold weather assembly is shown in Plate 1b.

(c) PROTECTIVE HELMET – The protective helmet is designed to safeguard the head from blows during buffeting or crashes. Ideally it should be light and shock-absorbent with a smooth hard surface to deflect blows and resist penetration. It carries the earphones of the intercommunication system and some form of visor, (see Plates 2, 4a and 12b).

(d) ANTI-GLARE PROTECTION – This is provided either in the form of sunglasses or a vizor, (see Plates 3, 2 and 13). In the case of sunglasses, different types of limbs have been designed for the spectacle frames according to the need for easy donning when wearing a close-fitting helmet (see Plate 3).

(e) OXYGEN MASK AND REGULATOR – Examples of a panel-mounted oxygen regulator and man-mounted miniaturised regulator are shown in Plate 5. Demand oxygen masks can be seen in Plates 2, 4b and 12b.

(f) FLYING BOOTS AND GLOVES – These are designed to protect the extremities during aircraft emergencies and in a survival situation (see Plates 6, 7 and 8).

(g) ANTI-G SUIT – This is a trouser-like garment of non-stretch material which may be cut away at the crotch and knees to permit greater mobility and also reduce heat load. On the inside of the garment are a number of interconnecting bladders which extend over the abdomen and legs. The function of the suit is to raise the wearer's threshold to the effects of radial acceleration (by about 1.5 G) and reduce associated fatigue (see Chapter 10). It may also be used, in conjunction with a pressure jerkin, to provide counter-pressure during positive pressure breathing (see Chapter 6). Examples of anti-G suits are shown in Plates 7 and 14.

(h) PRESSURE CLOTHING – Some form of pressure clothing is necessary to provide counter-pressure at high positive breathing pressures (see Chapter 6). This can take the form of a partial pressure assembly (see Plate 8) for emergency protection during descent after loss of cabin pressurisation at heights above 12 000 m (40,000 ft), or a full pressure suit which provides a stay-up capability (see Plate 9b). Examples of pressure helmets can be seen in Plates 9, 10 and 13.

(i) SEA SURVIVAL EQUIPMENT – Protection from low sea temperatures can be provided by an immersion suit. Flotation equipment, in the form of a life-saving waistcoat, is routinely worn when flying over the sea (see Plates 11, 12 and 13).

(j) AIR VENTILATED SUIT – This garment permits the passage of a ventilating air beneath the outer layers of clothing so that a supply of cool air can reach the skin. It is particularly valuable when rubberised garments, or items which contain a number of rubber bladders, are worn (see Plate 14).

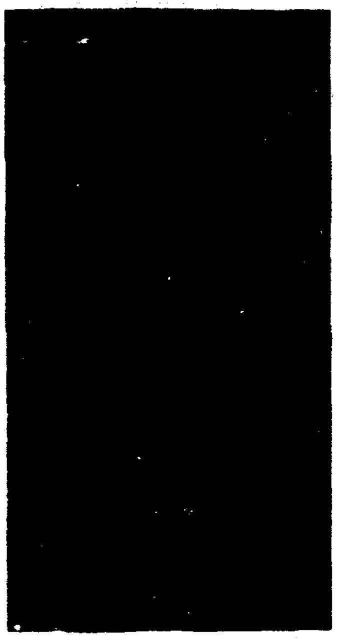
TRAINING

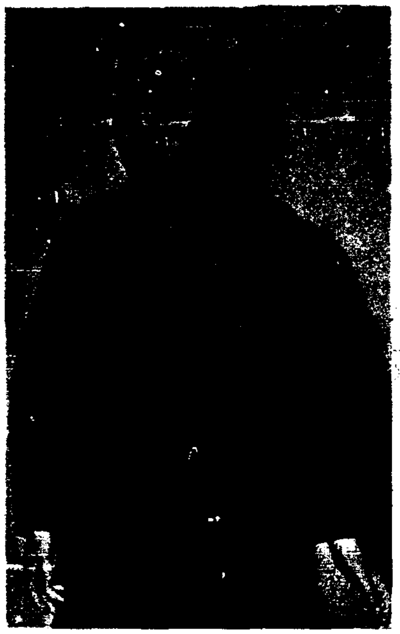
15. It is important to carry out regular ground training in the use of protective equipment. This will not only ensure that it can be used to its best advantage but also that the wearer will not be distracted from his primary task when using it in an emergency. The full flying clothing and personal protective assembly should be worn when carrying out this training, in order to discover any potential interaction difficulties with other equipment in the work-space.

CONCLUSION

16. Modern military aircraft are capable of high performance in both speed and altitude and can operate over very long distances; they are also more liable to damage than civil aircraft. For these reasons, flying clothing and protective equipment are an essential part of the aircrew way of life. The equipment must be kept in good condition and the wearer must be confident of his ability to use it in all fore-seeable situations, or its value will be lost and failures will occur when they are at least expected and least welcome.

- **ENSURE THAT CLOTHING ASSEMBLY FITS WELL AND IS COMFORTABLE.**
- **ALWAYS WEAR CORRECT CLOTHING FOR AIRCRAFT, ROLE AND AREA.**
- **ENSURE THAT CLOTHING ASSEMBLY IS WELL MAINTAINED.**
- **KNOW THE CAPABILITY OF ITEMS OF PROTECTIVE CLOTHING.**
- **PRACTICE WITH EQUIPMENT DURING TRAINING SESSIONS.**

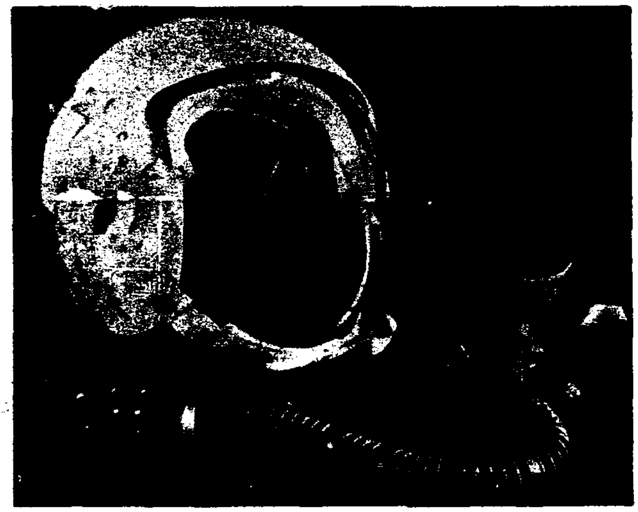




(a) This aviator is wearing a warm leather jacket over his orange-coloured light-weight flying overalls, (German Air Force).

(b) An example of a cold-weather flying suit for use in areas where the temperatures are particularly low, (Canadian Defence Forces).

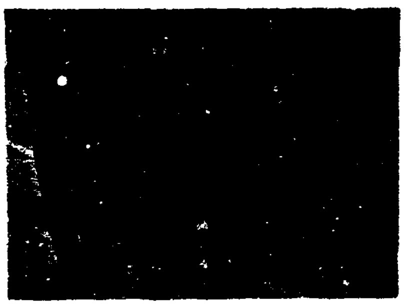
Plate 1 Cold Weather Flying Clothing



Examples of aircrew protective helmets with anti-glare vizors and oxygen masks; German Air Force (top) and Canadian Defence Forces (bottom).

Plate 2 Protective Flying Helmets

Sun glasses for IAF pilots. These are made of coloured optical glass, amber-brown in colour. The metal frame is designed to produce minimum disturbance with the field of vision in all quadrants. (Italian Air Force.)



Examples of different styles of spectacle frames. The 'limbs' shown in the left-hand example hook round the ears and make donning difficult when a helmet is worn. The right-hand example is designed to overcome this.

Plate 3 Tinted Flying Spectacles

(a) An example of a light-weight protective helmet with boom microphone, for use in helicopters, (Canadian Defence Forces).

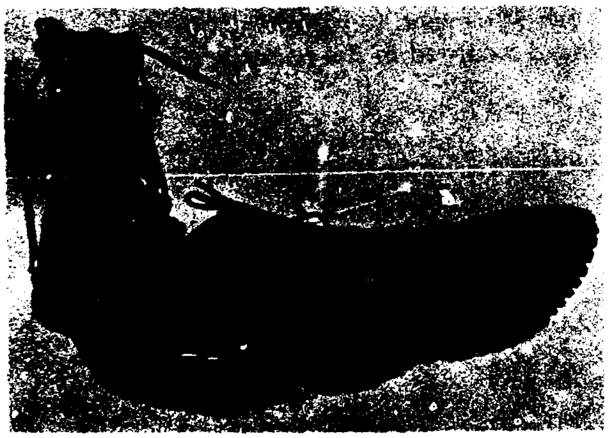
(b) A light-weight head-set assembly with a noise-cancelling boom microphone (in the raised position) whilst an oxygen mask is in use, (Royal Air Force).

Plate 4 Light-Weight Helmet Assemblies

(a) A demand oxygen regulator designed to be panel-mounted in the cockpit, (Royal Air Force).

(b) An example of a 'man-mounted' miniature demand oxygen regulator, (Royal Air Force).

Plate 5 Oxygen Regulators – Panel and Man Mounted



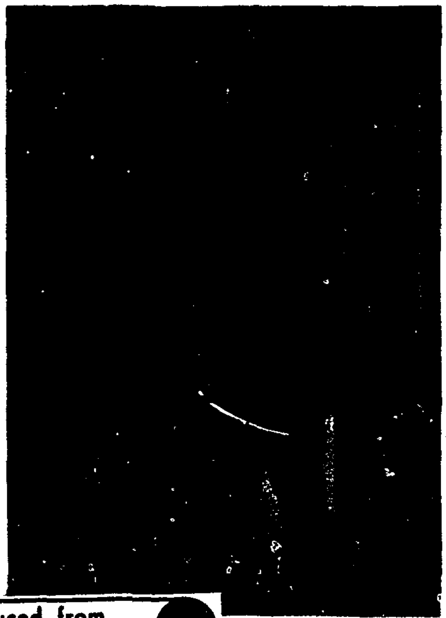
Examples of flying boots showing the current trend towards short close-fitting unlined boots designed to withstand the air blast after ejection. They are also made to suit the needs of a survivor walking over rough wet terrain, (Royal Air Force, top and German Air Force, bottom).

Plate 6 Flying Boots


Examples of 'external' anti-G suits from the German and French Air Forces respectively. An example of a type of anti-G suit designed to be worn under the flying overall can be seen in Plate 14 (right), (Royal Air Force).

Plate 7 External Anti-G Suits

(a) This aviator is wearing a partial pressure jerkin over a lightweight flying overall. In conjunction with his anti-G suit, it serves as a 'get-you-down' partial pressure assembly, (Royal Air Force).



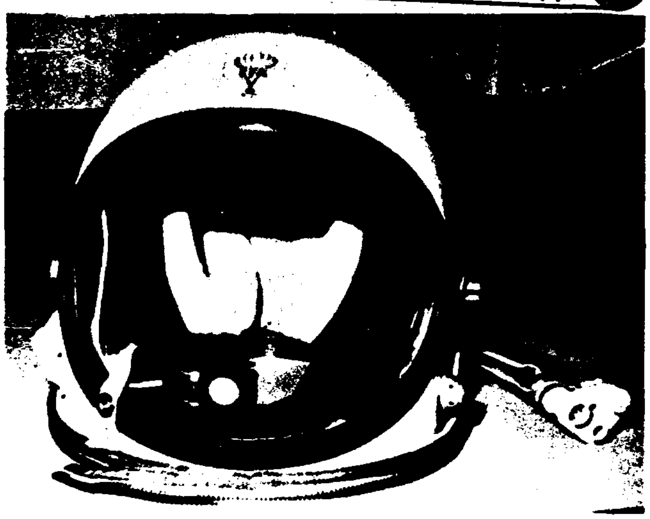
(b) An example of a high-altitude partial pressure suit with pressure helmet. This also shows a survival equipment seat kit (United States Air Force).

Plate 8 Partial Pressure Assemblies

(a) An over-garment forming part of a high altitude pressure suit assembly, (French Air Force).

(b) A full pressure suit, including pressure helmet and pressurised gloves, (United States Air Force).

Plate 9 Pressure Suits



Examples of pressure helmets from the United States Air Force (top) and the Belgian Air Force, (bottom).

Plate 10 Pressure Helmets

(a) An example of an inflatable life-saving waistcoat, (German Air Force).

(b) An aviator in icy water, wearing an inflated life-jacket and an immersion suit, (French Air Force).

Plate 11 Life-Saving Waistcoats

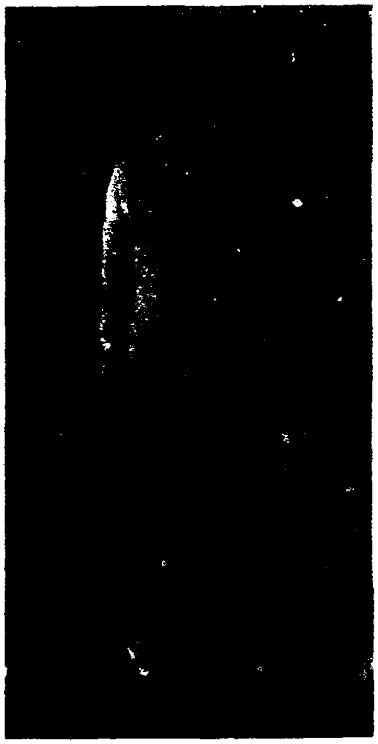
(a) Italian Air Force survival jacket for pilots. It is designed to be equipped with an emergency radio, emergency food and first aid materials.

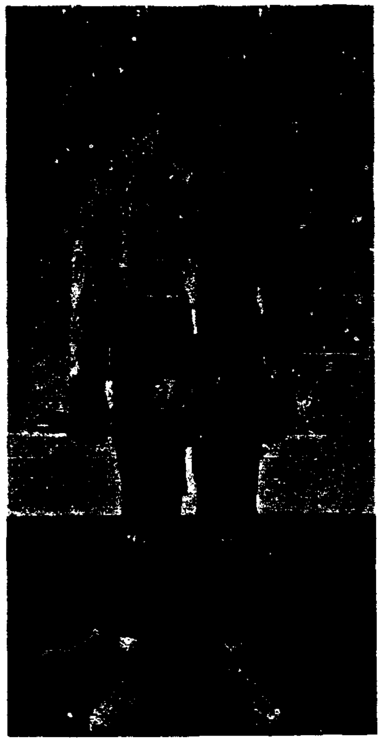
(b) An RAF inflatable life-saving waistcoat which is designed to withstand the effects of high speed blast on ejection.

Plate 12 Survival Jacket and Life-Saving Waistcoat

Examples of immersion suits (also known as anti-immersion suits) from the German Air Force and the Royal Air Force. These suits are equipped with rubber neck and wrist seals and in addition the rubber boots are sealed to the bottom of the trouser legs. On the left can be seen the special anti-exposure gloves which are supplied with these garments. The aviator on the right is wearing light-weight cape leather gloves at this stage. An example of a Royal Air Force partial pressure helmet can be seen on the right.

Plate 13 Immersion Suits





Examples of Royal Air Force air ventilated suits. These are made of nylon but cotton fabric is also used in other models. The picture on the right also shows an anti-G suit designed to be worn under the normal flying clothing.

Plate 14 Air Ventilated Suits and Anti-G Suit

TABLE 6

METRIC CONVERSION TABLE

LENGTH

1 nautical mile (n mile)	=	1852 metres (m)
1 kilometre (km)	=	0.621 mile
1 mile	=	1.609 km
1 metre (m)	=	1.094 yards (yd)
1 metre (m)	=	3.281 feet (ft)
1 yard (yd)	=	0.914 m

SPEED

1 knot (kn)	=	0.514 m/s
1 km/h	=	0.621 mile/h
1 mile/h (mph)	=	1.609 km/h
1 m/s	=	3.281 ft/s
1 ft/s	=	0.305 m/s

ACCELERATION

1 m/s^2	=	3.281 ft/s^2
1 ft/s^2	=	0.305 m/s^2
1 G	=	9.8 m/s^2
1 G	=	32 ft/s^2

PRESSURE

1 atmosphere (atm)	=	760 mmHg (or torr)
1 atmosphere (atm)	=	14.696 lb/in^2 (psi)
1 atmosphere (atm)	=	1013.2 millibar (m bar)
1 mmHg (or torr)	=	0.0193 lb/in^2
1 lb/in^2	=	51.715 mmHg (or torr)
1 gm/cm^2	=	0.0142 lb/in^2 (psi)
1 lb/in^2	=	70.307 gm/cm^2

TEMPERATURE

$$°C = \frac{5(°F-32)}{9}$$

$$°F = \frac{9(°C)}{5} + 32$$

TABLE 7

THE INTERNATIONAL SYSTEM OF UNITS (SI)

The metric system of units of the future is the Systême International d'Unités or International System of Units and the symbol used to describe this system is 'SI'.

The SI is based on six base units, namely:

MEASURE	UNIT	SYMBOL
mass	kilogramme	kg
time	second	s
length	metre	m
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd

Examples of supplementary and derived units are as follows:

volume	cubic metre	m^3
velocity	metre per second	$m\ s^{-1}$
acceleration	metre per second squared	$m\ s^{-2}$
angular acceleration	radian per second squared	$rad\ s^{-2}$
frequency	hertz	Hz
force	newton	N
pressure, stress	newton per square metre	$N\ m^{-2}$

Note: (1) The letter 's' is never added to the symbol to indicate plural.

(2) When unit symbols are combined as a quotient it is permissible, for example, to write m/s (as in the text) but $m\ s^{-1}$ is more correct.